Health & Safety Commission

Advisory Committee on Major Hazards

Third Report

The control of major hazards

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Preface

The Advisory Committee on Major Hazards was set up by the Health and Safety Commission towards the end of 1974 to consider the safety problems associated with large-scale industrial premises where potentially hazardous operations are conducted.

The Committee's first two reports, published by the Commission in 1976 and 1979 respectively, made important contributions to informed discussion and public awareness of the safety of hazardous industrial operations in this country. The reports included recommendations for a fairly wide notification scheme for major hazards, associated planning controls and hazard surveys.

This third report reviews the development of the main themes from its predecessors and presents a consolidated view of progress. It concentrates on the measures needed for the control over potential major hazards. The Commission welcomes the report as making a further important contribution to thinking in this field.

This is the Committee's final report as its remit came to an end in December 1983. Over the previous 9 years the expert views of a large number of people with different and often conflicting interests in this diverse and complex subject have been merged together. The ACMH has left us with much food for thought for the future and in particular directed our immediate attention to the potential hazards arising from the transport of large amounts of dangerous substances. The Commission has accepted this concern and has directed the HSE to examine how best to deal with this important aspect.

As well as the three reports, concrete results of the Committee's work are seen in the existence of a specialist unit in the HSE to deal with major hazards, the Notification of Installations Handling Hazardous Substances Regulations 1982, the forthcoming changes in planning controls and the implementation of the European Commission Directive on Major Accident Hazards: all these stem from the seminal work of the Committee.

Dr E J CULLEN
Chairman Health and Safety Commission

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The Advisory Committee

The committee was appointed by the Health and Safety Commission at the end of 1974 "to identify types of installations (excluding nuclear installations) which have the potential to present major hazards to employees or to the public or the environment and to advise on measures of control, appropriate to the nature and degree of hazard, over the establishment, siting, layout, design, operation, maintenance and development of such installations as well as over all development, both industrial and non-industrial, in the vicinity of such installations."

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C **Planning** Chairman: J M Miller
D **Research** Chairman: Professor J F Richardson
E **Specific Fire and Explosion Hazards** Chairman: V C Marshall
F **Transport** Chairman: Professor J L M Morrison

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Foreword

Our first[1] and second[2] reports to the Health and Safety Commission were published in 1976 and 1979 respectively. In these we set out to identify and obtain an understanding of the problems associated with the control of major hazards and we suggested a framework of legislative and other methods within which these problems could be contained. In this our third report we are concerned with the measures needed for their control. Of prime importance is the need for a better understanding by the general public of the nature of the risk imposed by major hazards and the methods taken to minimise and restrict them.

The main part of the report deals with the major issues to be considered in the control of major hazards and discusses various aspects of achieving improved control. The appendices cover various topics including scientific research and technical papers. These appendices have largely been the work of our sub-committees and many of our conclusions and recommendations in this report are based on this work.

The work of the sub-committees has been assisted greatly by co-opted members from industry and elsewhere and we gratefully acknowledge their contributions. The Health and Safety Executive (HSE) has also been of great assistance to us on a continuing basis and we would offer thanks to the many officers of the HSE who have generously helped us. Finally, we must record that all our deliberations have been aided by the outstanding contribution of our secretary and his staff, not only in relation to the day to day work of the committee, but also and not least in the preparation of this report. To them we offer special thanks.

1 The overall problem

1 This report continues to deal with our task of considering those installations which could present a major threat to the safety of employees or the general public from explosion, the release of toxic substances, or catastrophic fire*.

2 The phrase 'major hazard' was coined in the context of possible accidents in chemical or other industrial installations handling dangerous substances which might cause extensive damage and kill or injure persons within or outside the site boundary. Interest and alarm were generated not least because the potential off-site effects raised new questions about the measures that existed or could be introduced to ensure the safety of members of the public in the vicinity of such installations.

3 The aspect central to our discussions has been the question of risk. Much has been written about risk in recent years, and it would be easy to think that risk is something new that we have invented in the last few decades. On the contrary, man has always had to live with risk, and each generation has had to come to terms with its own particular, and often new, problem. We believe it to be sensible to take the attitude that the risks from modern technological processes should not be the dominant risks for a worker or the public; indeed that they should not add significantly to the risks from all sources to which each of us is exposed throughout his life. This is discussed more fully in the next chapter, and much of what follows is concerned with the practical, and essentially commonsense, measures which can be taken to achieve a low level of risk.

4 Our 1976 and 1979 reports set out the problems involved, and suggested legislative and other measures to control or contain them. We suggested ways and means of identifying those activities which posed the greatest potential hazards to both workers and the public at large, and stressed the need for improved controls over the design, operation and siting of such activities. We recognised that absolute safety was impossible to achieve and in order to provide an adequate system of control, made a number of recommendations most of which we are pleased to note have been acted upon. The introduction of the Notification of Installations Handling Hazardous Substances Regulations 1982 (hereinafter referred to as NIHHS Regulations) by the Health and Safety Commission (HSC) which we recommended in our first report together with proposals for changes in planning legislation by the Department of the Environment (DoE) and the Scottish and Welsh Offices are seen as important achievements in the control of major hazards. The identification of the substances which would pose the greatest threat to safety and the choice of threshold quantities for them have been difficult, but we hope and believe that our judgements have gone some way towards achieving a reasonable degree of equivalence of hazards.

5 The European Community Directive on the Major Accident Hazards of Certain Industrial Activities[3] (hereinafter referred to as the Directive) was adopted by the European Community in June 1982. Although we have reservations about some proposals in detail, we are pleased that many of the Directive's requirements stem from and reflect our views in the earlier reports. This Directive requires further controls over larger quantities of the hazardous materials listed in the NIHHS Regulations. It also extends controls to other, similar hazardous substances and to a large number of toxic chemicals as well. The main provisions of the Directive include duties on the person in control of specified activities using scheduled substances to make a report to the competent authority (in this case the HSE) identifying the major accident hazards and the measures taken to prevent them, or to control and minimise their consequences; to draw up an emergency plan for use within the site and to provide information for dissemination to members of the public who might be affected by an accident at the site. The Directive also requires a competent authority to draw up an emergency plan for use outside the site. A summary of the main provisions of the Directive is given in Appendix 3. The Directive will be implemented by the Control of Industrial Major Accident Hazards Regulations.

6 However sound the statutory requirements are, or excellent the technology, unless society in general has confidence in them, effective control will not be seen to be achieved. This is particularly true for major hazards, and it therefore is our view that open debate should be encouraged at all levels. The point is made that people who are liable to be affected by a major hazard installation should have information made available to them on the hazards and the control measures. The problems are by no means simple and these are considered more fully in Section 2.

7 This report is entitled *The Control of Major Hazards* and we consider there to be four basic elements of a control scheme. Firstly, it is necessary

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* See Glossary for definitions, acronyms and abbreviations used in this report.

that activities with the potential for creating a major hazard can be identified. Since 1 January 1983 HSE is provided under the NIHHS Regulations with details of all installations defined as hazardous. Secondly, when dealing with any activity which might be dangerous it is essential to recognise the potential hazards and the ways they might be realised, and to assess them. We deal with these topics in Section 3. Thirdly, one should try to eliminate or avoid the potential hazard, but if this is not reasonably practicable then every attempt should be made to reduce the probability of its occurrence or its scale. These matters are discussed in Section 4. Fourthly once identified and assessed, the hazardous installation and its relationship to the surroundings can be examined. In Section 5 we consider proposals for technical guidelines which HSE is developing as the basis for its advice to the planning authority to take into account with all other factors when it makes its planning decisions about such developments. This section also discusses the means that could be taken to mitigate the consequences of a potential major incident. Our views on proposals by the DoE to improve the control of development both at and in the vicinity of such installations are set out in Section 6.

8 In developing the hazard controls which we describe in this report we have aimed throughout at a system which is robust. We have sought to achieve this by using a variety of measures which complement and support each other and which avoid excessive reliance on any single one. This is the approach which has been used with great success in the detailed reliability engineering of hazardous plants and other high technology systems and we think it is equally applicable to the overall system of hazard control.

9 The education in matters of safety of those involved in major hazards is essential and must continue. Our views are given in Section 7.

10 Continued research into factors affecting major hazards is necessary. This will contribute to a better understanding of the causes of accidents involving major hazards and enable safer designs or procedures to be adopted. It may also allow some of the calculations in the assessments to be made with less pessimistic assumptions.

11 The transport of dangerous substances is a matter of growing concern and we have taken this opportunity of including our 1982 Report on this to the HSC as Appendix 2. Our Report makes a *prima facie* case that there are aspects of the transport of dangerous substances in large quantities which merit the same degree of attention that is paid to similar quantities in static installations. The main aspects that we highlighted for further consideration include:

(a) the need for hazard surveys for large quantities of hazardous substances in transport including any intermediate storage facilities;

(b) the need for planning controls for transit depots and loading or unloading sites and for nearby developments, similar to those being introduced for other notified sites, and

(c) the system of control and responsibilities for safety in ports and harbours handling major hazard quantities of hazardous substances.

The Commission has agreed that the areas we identified as requiring further study should be followed up.

12 In our earlier reports we recommended that there should be further investigations into the causes, behaviour and consequences of dust explosions and catastrophic fires, including fireballs, fire storms and the so-called 'domino effect'. Appendices 8 to 10 describe the results of our work and our principal conclusions are that:

(a) Although fireballs are a well-established phenomenon, further work is necessary to develop improved methods of predicting their effects.

(b) Fire storms are unlikely to occur as a result of conventional fires in modern industrial plant. However, the effect of large scale spillages of liquid oxygen merits further investigation.

(c) Dust explosions usually have only local effects. The hazards appear to be well controlled by Section 31 of the Factories Act 1961, which is now part of the Health and Safety at Work etc Act 1974 (hereinafter referred to as HSW Act).

(d) Anyone operating a major hazard plant should consider the effects of major accidents on other plants on the site or nearby sites (the so called domino effect); all those affected should plan accordingly to minimise the consequences.

13 Since our last report a fire occurred at Morley near Leeds as a result of which toxic chemicals were released into a water course. After studying all available information on the incident we decided there were a number of issues on which we would like to express our concern. A brief report is at Appendix 4.

14 We have also included as Appendices 5, 6, 7, 12, 13 and 14 accounts of some of the various research projects that we have learned about since our last report.

2 Living with risk

15 We are all throughout our lives subject to risks. Some are perhaps inescapable and must therefore be accepted; others might be reduced in frequency or magnitude sometimes at the cost of eliminating compensating benefits. It is our view that the principle of balancing the efforts required to reduce risk against possible gains has been part of our common duty of care for generations and is certainly part of the concept of "reasonably practicable" in the HSW Act. We think that the same approach should be followed in the field of major hazards.

16 The obverse of risk is of course reliability and it is with the reliability of major hazard installations that we have been concerned. The duty laid upon employers by the HSW Act requires employers to ensure, so far as is reasonably practicable, the health, safety and welfare at work of their employees. The Act also requires employers to conduct their undertakings in such a way as to ensure, so far as is reasonably practicable, that other people who may be affected are not exposed to undue risks to their health or safety.

17 "Reasonably practicable" has been defined by the Court of Appeal and we think it valuable to repeat the definition here. In the case of Edwards versus the National Coal Board (1949)[4] Lord Justice Asquith interpreted "reasonably practicable" to imply that a computation must be made in which the quantum of risk is placed in one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them — the risk being insignificant in relation to the sacrifice — the defendants discharge the onus upon them. Moreover, this computation falls to be made by the owner at a point in time anterior to the accident. The wording of the HSW Act is no more than a restatement of the duty of care under the Common Law which applies to us all. It is clear that in some circumstances the High Court ruling would prohibit the activity altogether if the risk could not be controlled within financial limits which were commercially acceptable. In our 1976 report we suggested tentatively that there was a level of risk or reliability, as the case might be, which we saw as the lower limit of acceptability. It made clear also that there were circumstances and conditions where higher levels of reliability would be both reasonable and practicable and this was a matter which would have to be judged in each individual case. The duty of care on individuals and the statutory duties laid on employers both provide for "reasonable and practicable measures", and these by the very nature of the judgement referred to above will vary with the intensity and magnitude of the risk, becoming increasingly onerous with each increase in risk; with that in mind we think there is no need to go further. It does not therefore seem feasible to us to attempt to lay upon individuals or corporations "duties" which they cannot discharge. It would not be helpful to "require" a major hazard plant to be "safe". It is true that in safety legislation, absolute duties in some cases have been laid upon employers; for example the fencing of dangerous machinery under the Factories Act. However it is notable that the courts have interpreted this duty as being modified by what is "foreseeable" as to danger. From the point of view of major hazards the case of Bolton v Stone (1951)[4] is relevant. In this case Lord Porter observed: "Nor is the remote possibility of injury occurring enough. There must be sufficient probability to lead a reasonable man to anticipate it. The existence of some risk is an ordinary incident of life, even when all due care has been, as it must be, taken." The judgement is interesting in that the phrase "sufficient probability" is here used, in a legal context.

18 The use of the word "probability" can also infer the quantification of the likelihood of given events which, with the assessment of the potential consequences of the hazards, have been of particular interest and study in recent years. We deal with the subject of quantitative assessment in the next section where we consider use of quantification techniques to achieve a greater understanding of hazards and risks and hence the ways in which they can be avoided. Much has been written on the subject and it is one on which many disciplines have a contribution to make. However the results of quantification must be seen in context and treated with caution and proper understanding.

19 In dealing with the risks the decision-maker needs to take into account the different perceptions of risk and to be mindful of the many facets of the risk problem. It is not appropriate to treat particular figures as rigid limits of acceptability or to take too mechanistic an approach. The problem of risk was discussed in a 1983 Report by the Royal Society.[5] The following quotation from the section on "Possible quantitative guidelines" summarises some of the factors which need to be considered:

"With all this in mind, it still seems worth discussing some typical figures which Government or regulatory agencies could bear in mind, both in judging the impact of individual hazards, and in judging whether risks of catastrophe are tolerable or not.

"Such figures can be no more than broad guidelines to the decision-maker for several reasons:

(a) Each case must be regarded on its merits. Significantly different quantitative guidelines might well apply to different situations.

(b) The figures must necessarily refer to objective estimates of risk. But since individual perception (and indeed individual estimation of risk) covers such a wide range, a rational central decision, even if further modified by some allowance for differences of perception is bound to leave some people considering that they are at undue risk.

(c) The individual perception of being at risk is likely to be reduced by consciousness that efforts are being made to improve the situation.

(d) The central decision-maker may take a different view from that of the industrialist whose risks he needs to regulate. He may well impose controls which are more stringent than appear necessary to the industrialist. But this need not always be so. For one thing, government action may be unduly delayed; for another, a manufacturer will often, in his own interests, wish to control stringently a commercial product which might react on the manufacturer's good name or an individual's conscience.

"With all these qualifications, the decision-maker should have in mind an upper value for the risk associated with particular hazards which must not be exceeded. If an activity cannot be controlled so that the risk comes below that level of risk in a reasonable time, it should be stopped. By contrast, there is almost certain to be a lower level of risk, below which further control would be a wasteful deployment of resources. This level appears as a trivial one to the decision-maker — though it may not appear trivial to some of the individuals at risk. For certain hazards which are very salient in the public mind, significant sections of the population may continue to be concerned, whatever the level of risk, however small. The decision-maker has to bear this in mind, but in our view it is between these upper and lower limits that the risks, detriments, costs, and benefits need to be related, and the concept of control 'so far as is reasonably practicable' becomes relevant."

20 We believe that there is less scope in setting a risk criterion than is sometimes acknowledged in discussions of the subject. Most major hazard risks fall in the band between the clearly unacceptable and the clearly negligible. Within this band there is a region of uncertainty and the acceptance of a particular situation will depend upon a whole range of factors. These might include such aspects as whether the plant is a new or an existing installation, whether it is a single or multiple installation, the siting, the level of confidence obtained from the safety assessments, the benefits and the availability of alternative processes.

21 In the context of the control of major hazards we believe that there is widespread support for the following propositions.

(a) The risk from a hazardous installation to an individual employee or member of the public should not be significant when compared with other risks to which he is exposed in everyday life.

(b) The risk from any hazardous installation should, whenever reasonably practicable, be reduced.

(c) Where there is a risk from a hazardous installation, additional hazardous development should not add significantly to the existing risk.

(d) If the possible harm from an incident is high, the risk that the incident might actually happen should be made very low indeed. This takes account of society's particular abhorrence of accidents which cause many simultaneous casualties.

Information to the public

22 It seems inescapable to us that if the public are to be expected to live with risks from some industrial installations, however well controlled, they should be made aware of those risks. But there are considerable practical problems: what information should be given; who should be told; who should do the telling, and, by no means least, for which installations should information be given?

23 As to what information should be given to the public nearby, we think that the minimum information given should include:

(a) the nature of the hazards which might affect them if control measures fail;

(b) the emergency arrangements which have been made in advance, and

(c) what they should do in a major incident.

24 When it comes to deciding who should be told we think there are three broad categories.

(a) Employees and others on the site.

(b) Local planning authorities and emergency services.

(c) Members of the public who live in the vicinity of a hazardous installation.

25 There are no difficulties about informing employees and others on the site, since those concerned are covered by the duties and requirements of the HSW Act. There are no great difficulties either with the local planning authorities and emergency services, since Section 28 of the Act allows the HSE to pass on the necessary information. The NIHHS Regulations have helped in this respect as the HSE has

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made arrangements to pass information about a notified installation to the local authority's planning department and fire service. The remainder of the answer to the question 'who should be told' is less straightforward. We think that the need to know should be the guiding principle but it should be applied flexibly. The withholding of information on a technicality might create a spurious air of secrecy which could be counter productive. For appropriate sites the carrying out of safety assessments and the drawing up of emergency plans will effectively define the areas near the installation which might be affected. In our view this broadly defines the members of the public who should be told.

26 Next, who should be responsible for generating and passing on the necessary information? In the first instance the information must originate from the manufacturer but there is no overriding reason why he should also disseminate it. As a Committee we are inclined toward leaving this latter function to local authorities, chiefly because they will be close to those concerned as they are the public's representatives in local matters. But we do not know how this would be done or whether this would place significant extra burdens on some authorities and we have not thought it necessary to make specific enquiries. The alternative is that this duty should also be placed on the manufacturer. We note that the HSC has indicated these alternatives in its Consultative Document on the Directive[6] and we think that the comments they receive are likely to be well informed. We therefore hesitate to make a firm recommendation.

27 All these matters are in principle contained in the Directive which also defines the installations for which information should be given to the public. They are therefore to some extent a *fait accompli.* Individual states will, of course, decide how they implement it but we welcome this European initiative and the proposals for implementation which the HSC has published.

28 We have however considered whether the arrangements required under the Directive should extend to other sites identified by the NIHHS Regulations. We think it would be unreal to suggest an across the board application to all such sites. While an incident in any of them might well involve one or more of the emergency services, the public's involvement may be negligible. We therefore think that the information requirement of the Directive should be applied to Notifiable Installations only when the authority charged with implementing the Directive (the HSE) thinks it appropriate to do so.

29 We believe that there should be informed debate about the hazards. This may require the dissemination of information beyond the needs of dealing with an emergency and something more than the implementation of the Directive.

30 At the present time we believe the public is given information about sites and their hazards on an inconsistent basis. Some operators make considerable efforts to establish a good relationship with their neighbours through booklets, meetings and open days. Other operators are less willing to give information in case security or commercial confidentiality is threatened and others have regard for the fears and suspicions that could be generated amongst members of the public by disclosure about processes and their potential hazards. There is also the danger of information reaching subversive organisations.

31 The fact that some of the most successful operators in this industry are the most forthcoming with information suggests that the fears of the others may be exaggerated. Nevertheless we appreciate that they are real and would not wish to dismiss them. Commercial confidentiality may be a matter of vital importance to some companies and we acknowledge their need to safeguard their information.

32 When it comes to the question of causing unnecessary alarm, a fear which some operators have expressed, we are less readily convinced. We believe, on balance, that information presented in a straightforward and above all objective and factual way without too much reassuring comment is likely to be readily acceptable and more likely to reduce rather than increase anxiety.

33 While we are agreed that there is need for the dissemination of some information which goes beyond that required by the Directive if our wish to stimulate informed debate is to have any meaning, we are only too aware how easy it is to pronounce on general principles without indicating how they are to be applied. Indeed when it comes to detailed implementation we find ourselves on a less sure footing. The questions how much, to whom, by whom and for which installations, are crucial to the whole problem but evoke no easy answers. It may be that the wide differences between one installation and another, especially the essentially local factors, mean that no single prescriptive solution is a practical possibility. This lends weight to our view that the solution must emerge locally, perhaps from a local liaison committee. Such arrangements work well, we understand, in the nuclear industry and despite the intrinsic differences are worthy of consideration for the hazardous industries with which we have been concerned.

34 We are aware that Section 3 sub section 2 of the HSW Act gives power to make regulations on this very matter but the fact that in a decade the HSC has not seen fit to recommend its implementation to the Secretary of State suggests that appreciation of the difficulties is not confined to members of this Committee. Our terms of reference also create difficulties. While we strongly urge that the industries with which we have been concerned should seek to extend and strengthen the voluntary arrangements already in existence, perhaps encouraged by their respective trade organisations, we are hesitant to suggest that a statutory obligation should be placed upon any one group of employers before the wider implications have been considered. Many industries

with risks to the public other than the ones pertinent to our considerations are involved; nuclear energy is a specific example which may well present difficulties of which we are unaware. We think however that this is a matter of considerable importance and that the HSC should give urgent consideration to the problems involved with the implementation of S.3(2) of the HSW Act to see whether there are requirements which should be applicable to all industry. A universal statutory obligation would do much to avoid emotional reactions which might result if a single industry were singled out for special treatment.

35 We summarise our discussion by recommending the following.

(a) Unless responses to the HSC Consultative Document suggest otherwise, local authorities and local industry should devise systems to provide information to those members of the public likely to be affected by major accidents, in accordance with the requirements of the Directive.

(b) The information requirement of the Directive should be applied to notifiable installations when HSE think it appropriate to do so.

(c) Local liaison committees should be set up for notifiable installations, where appropriate, to bring together the public, industry, the emergency services and the HSE.

(d) Voluntary arrangements for the supply of information to the public which go beyond what is needed for emergencies under the Directive should be extended and encouraged by trade associations.

(e) The HSC should re-examine its powers under the HSW Act and consider whether regulations are required to secure the provision of specific information to designated recipients.

3 Recognition and assessment

36 In any system of control for major hazards, the first step is to establish suitable criteria to recognise those installations which present the greatest potential threat to safety. In our previous reports we considered ways in which these criteria might be chosen and included proposals based on a list of substances and their threshold quantities. The threshold quantities were in two parts; at the lower level an installation would be notified to HSE, and at the higher level (ten times that for notification) a hazard survey would be carried out. This procedure, though far from ideal, took account of the limited technical expertise available within industry to carry out these hazard surveys and within HSE to examine them.

37 It is pleasing to record that these proposals with a few amendments have now been adopted in principle, firstly in the NIHHS Regulations and secondly in the Directive (see Appendix 3) which deals primarily with installations which hold substances in quantities which will require a hazard survey. While the Directive appears to derive from the views we developed on recognition of major hazards, we still consider there are fundamental problems concerning recognition and assessment of major hazards. The main points include:

(a) how to equate different types of hazards;

(b) how major hazards might affect the environment;

(c) the relative danger of storage of a substance as against its use in a process, and

(d) assessment of hazards and risks.

38 There are many difficulties and uncertainties in establishing the equivalence of different hazards. One approach is to examine the information available from past major accidents. However, for some substances this information is lacking or incomplete and judgement must be exercised to consider the likelihood and consequences of accidents when deriving threshold quantities for these substances. Other approaches are more theoretical and have, for example, been based on estimates of the amount of a substance which will damage a defined area or cause an arbitrary number of casualties.

39 For certain classes of substance, e.g. those with flammable, explosive or highly reactive properties, historical experience can be backed up by calculating the likely physical consequences of an incident. The energy produced by the combustion of a flammable material or the decomposition of an unstable substance can be compared with the energy produced by the decomposition of an explosive. Different quantities of substances which are involved in explosions are also subject to scaling laws. There are no similar methods for estimating the effects of toxic substances, however, since the physiological effects of these substances are almost as varied as the chemicals which may be released. Thus difficult problems arise in comparing the major hazard potential of one toxic substance with another and then establishing an equivalence of hazard with substances in other classes.

40 The Directive effectively divides toxic substances into two groups. The first group contains toxic substances, including liquefied gases and liquids of high volatility, which are handled in bulk quantities. The second group, which contains substances with highly toxic properties, includes solids and liquids of low volatility. We note that the threshold levels which have been assigned by the Directive to the first group are broadly in line with the proposals which we made in our Second Report. On the other hand many of the threshold levels which are assigned to the highly toxic substances are as low as 1 kg. When this level is compared with the 50 tonnes assigned to chlorine it suggests that these substances are regarded as being 50 000 times as dangerous as the latter even though they may possess very low dispersive energy.

41 We agree that dioxin, because of its highly unusual properties, should be controlled at this level but it is our view that few other substances in Annex III of the Directive display a similar combination of toxicity and persistence. We note also that some of the substances listed are carcinogens of low acute toxicity the harmful effects of which require months or even years of exposure. We have not considered such substances in the past as constituting major hazards and see no logical way of including them in the category of major accident hazards. Insofar as the UK is concerned we consider that the existing means of regulation under the HSW Act are adequate, and even to be preferred, for dealing with dangerous carcinogens.

42 When the Directive is reviewed we would recommend strongly that a more practical approach should be adopted. We would like to stress that the threshold quantities for most of these highly toxic substances are far too severe[7-8]. A matter of great importance however is that there are no clear guidelines to assess equivalence of hazard for these and other toxic substances and, at our instigation, HSE is sponsoring research on this topic. The research will be aimed at the development of two sets of criteria which ought in combination to provide clear

conclusions from which hazard levels can be categorised.

(a) The first set of criteria should set out the factors from which an assessment of intrinsic toxic properties can be made. The original work will be concerned with lethal effects but this will be extended, at a later stage, to include an examination of non-lethal effects.

(b) In the second the exposure characteristics of the substance will be assessed taking into account such factors as volatility, dispersion and persistence.

Environmental major hazards

43 Under the terms of our original remit we were asked to identify installations presenting a serious threat to employees, the public, or to the environment. We have concentrated mainly on effects on man, but the provisions of the Directive specifically draw attention to the protection of the environment from the effects of major industrial accidents. Major hazard accidents are sudden, acute events while serious accidents to the environment are generally the result of prolonged releases of perhaps only small amounts of toxic material causing long term damage. Rapid releases of large amounts of toxic material do not necessarily cause acute or long term environmental effects and we found it difficult to define precisely an environmental major hazard in a way which would achieve general acceptance.

44 The problem could be approached from a purely financial aspect. For example, an environmental major hazard accident could be defined as an event costing more than about £10 million or some other arbitrary amount but it is seldom possible to place value on gross insult to the environment.

45 We suggest that an environmental major hazard accident is most likely to occur when sudden emission of material causes long term or widespread damage to cash crops, farm animals, natural amenities (wild life) or contamination to land or water. The extent of the damage will depend on the characteristics of the material released, including its toxicity, persistence and ability to disperse.

46 Substances expected to be most readily dispersed on loss of containment include gases held at pressure and fluids handled or processed at pressure above their atmospheric pressure boiling points. However as regards persistence, which in this context may be paramount, involatile liquids or solids may be of greater importance, but they would require an external agent for their dispersion.

47 In the absence of suitable bunding, liquid materials can be dispersed by simple loss of containment, especially if a water course is reached. Wind, explosion, or fire will disperse particulate materials. Severe fires can have several effects. The high temperatures produced cause convection currents capable of lifting solid and liquid particulates to considerable heights and can also cause chemical changes in the materials involved, resulting in modification of their environmental toxicity. Furthermore the large quantities of water often used to fight such fires can by drainage introduce toxic materials into water courses (see Appendix 4).

48 Having considered the methods of dispersal set out above, we think that most, if not all, accidents affecting the environment will also affect man, and therefore we believe that measures taken to protect man will for the most part also protect the environment. In the few possible circumstances where this might not be true we think the evidence available is not sufficiently reliable for us to make further recommendations. We think the subject should receive further attention some time in the future.

Storage and process

49 We have based our criteria for major hazard installations on the inventory of hazardous substances, taking into account the physical properties of the substance and the type of hazard it presents. We have not differentiated between materials used in process and those held in storage. We noted that in discussions of hazards in the oil and chemical industries it is sometimes suggested that the risk from materials in storage is less than that from materials in process. The historical record appears to indicate that storage facilities account for an appreciable proportion of the accidents causing multiple deaths, say five or more. We adhere therefore to our original view that there is at present no case for distinguishing between materials in process and those in storage.

50 The Directive draws a distinction between isolated storage and other storage and specifies for the former larger threshold quantities, implying that the risks are less for such storage. Certainly isolated storage is by definition less at risk from process interactions, but on the other hand it is often managed by a company which is not in the mainstream of the oil or chemical industries and which is likely to be less familiar with the techniques of major hazard control. Again, therefore, we think that the case for a distinction has not as yet been made.

Assessment and quantification

51 Having identified a potential hazard it is then necessary to assess its seriousness and decide what should be done about it. This involves forming a judgement as to how real the danger is and the need to be able to do this has led to the development of formal assessment techniques. The expression 'hazard assessment' is modern jargon but civilised man has always striven to quantify the world about him in order to improve his understanding of it and to make use of his environment. Hazards and risks have been subjected to more detailed analysis in recent years but the resulting quantification should be seen in context as a means to an end and not an end in itself.

52 In today's world, technology is becoming increasingly safe, and will continue to improve not only as the lessons of the past are applied to new ventures but as improved techniques are applied to assessing the risk of failure of any design and the consequent safety factors which must be built into the completed enterprise. The search for engineering reliability is as old as technology itself. In the past boilers exploded, bridges collapsed and ships sank. Each generation tried to learn from the mistakes of the past and to make new designs safer. This often led to crude increases in the strength of components; less frequently was there scientific appraisal of the underlying causes of failure. When we recommended in our 1979 Report that a major hazard plant should be the subject of hazard assessment we were doing no more than following an established and commonsense approach but with the assistance of more numerous and sophisticated techniques than formerly.

53 Today there is increasing emphasis on the assessment of hazards and risk in quantitative terms. This may be limited to the estimation of the frequency of loss of containment, or it may go on to evaluate the physical consequences and in turn the dangers to employees or to the public. As far as frequency of a major incident occurring is concerned the estimates may well be fairly straightforward and can be derived from fault trees and the probability data for component failures. The depth of an analysis will depend to a large extent on the assessor's view of the accuracy of his data and the purpose of the assessment. In this respect his judgement will vary according to whether he is seeking to increase plant reliability, to satisfy a public inquiry or to meet regulatory requirements, any one of which may be the most demanding, depending on the circumstances.

54 At some stage in the evolution of the chemical industry it was recognised that its particularly hazardous processes should be fitted with automatic shutdown systems. This in turn led to the use of disciplined techniques such as fault tree analysis to show the fault pathways qualitatively and to develop suitable instrument configurations. The fault trees were then used quantitatively to assess the frequency of system failures leading to loss of containment or other major accidents. This led to a need to devise a risk criterion against which to assess the cost effectiveness of proposed safety alternatives. One such criterion was the fatal accident rate for employees.

55 This early work was followed by a rapid increase in the application of the techniques of reliability engineering generally, to all kinds of engineering problems within the chemical industry, including those of plant availability and maintenance as well as of safety. Information and experience in this field has been fed back into the hazard assessment which is now an established part of engineering decision making when hazardous substances are involved. It assists in identifying the significant hazards, in choosing cost effective countermeasures, and in bringing out the underlying assumptions and the conditions which must be met if the hazard is to be properly controlled.

56 Hazard assessment involves the consideration of a variety of potential accident sequences and the estimation of their frequency and consequences. The consequences may be expressed in various ways. A common form of presentation is to show a contour giving the risk of a defined level of physical effect on a map of the site and its environs. The analysis may be extended to provide an estimate of deaths and injuries or damage to property and thus of individual and societal risks. Great care is needed if this is done however, because the assumptions made are particularly critical and also because the models available to translate physical effects into fatalities etc. are subject to particular uncertainty. Frequently it is sufficient to make an order of magnitude estimate of the consequences so as to ensure some degree of balance in the effort employed to reduce the risk. Examples of these different types of presentation are given in the Rijnmond[9], Canvey[10], and St Fergus-Moss Morran Reports[11].

57 In general greater benefit is derived from the quantitative assessment of events leading up to loss of containment than from that of the subsequent events. There are a number of reasons for this, some fundamental, others perhaps less so. One is that management is able to exert considerable influence on the events prior to release but little on those thereafter. Another is that the degree of uncertainty in the estimate increases rapidly as the chain of events lengthens. Yet another is that the criteria for evaluation become increasingly subjective the further down the chain the assessment is taken.

58 Whilst we generally recommend the use of quantitative techniques, we appreciate that they may pose difficult problems. The historical data on which estimates of frequencies, or probabilities, are generally based may be limited or open to doubt. If synthetic methods such as fault trees are used, there are the additional difficulties of identifying all the failure modes and of handling features such as common cause failure and human error. The models which are used to estimate the consequences, whether in terms of physical effects or of harm to people, are subject to uncertainty in varying degrees. There is also the crucial matter of the assumptions which are made. In hazard assessment there is a danger of making simplifying assumptions which lead to extreme and unrealistic results. Dangerous situations may be underestimated, but perhaps more frequently worst case assumptions are made which lead to predictions which are excessively pessimistic. A limit case approach has its uses, but in general a realistic assessment is preferable.

59 It is widely held that the value of a quantitative assessment is not simply the calculation of a set of risk figures which meet some arbitrary criteria. Of prime importance is the greater understanding which is gained in the course of the work. This, in turn, leads to improvements being made. We have much

sympathy with this view. The assessment is not just a numbers game; nevertheless, we think that the risk estimates obtained cannot simply be disregarded. They should be evaluated in some way and the evaluation should be one of the factors considered in making the decision. At the same time when considering the application of any criterion it is necessary to bear in mind that the discipline of quantitative assessment is still developing rapidly. In our view, therefore, it is necessary to proceed with caution in the use of risk criteria to evaluate current assessments since there is still a considerable degree of uncertainty in these. We have outlined some principles on which criteria may be based in Section 2.

60 We acknowledge that there is currently a lively debate among engineers on quantitative assessment and in particular on its role in the public domain and in regulation. We think, however, that it would be a pity if disagreement over this quite limited area were to hinder the development and application of this most useful tool for the control of hazards.

61 Quantitative analyses require considerable resources of skilled manpower. We believe, however, that as the discipline matures many aspects will become more routine. It is not, of course, desirable that the whole analysis becomes routine, since a principal objective is to increase understanding of the plant, to identify hazards and to effect improvement. Nevertheless, in due course a larger quantitative input will be possible with greater economy of resources.

62 One use of quantitative assessments on which we specifically wish to comment is with regard to statutory control. In both our earlier reports we expressly recommended that persons in control of hazardous installations should demonstrate to the HSE that the hazards have been identified and all reasonably practicable measures taken for their control. In particular it was always anticipated that the hazard surveys which are recommended would in part be based upon some form of quantitative assessment. We still hold this view.

63 In order to facilitate this process we believe that the HSE should develop and make known the guidelines of what is good current practice. We also think that, wherever possible, the HSE should release the results of case studies as they did for the St Fergus to Moss Morran pipelines and Canvey.

64 Finally we re-emphasise that the use of quantitative techniques is only one useful element in the overall system of control and only one input to be considered in decision making on major hazard plants. The main benefit in estimating risk lies in the achievement of detailed understanding of the engineered system and the implications of various options for technical measures and for siting.

4 Avoidance

65 If it has been established that a major hazard exists, the next step is to attempt to eliminate it or to reduce the frequency or probability of its occurrence. We attach the highest priority to the avoidance of accidents. In this section we consider three approaches to this objective:

inherently safer design,

high reliability plant and

learning from warnings.

Inherently safer design

66 An important lesson drawn by engineers from the Flixborough disaster of 1974[12] was that a hazard potential may be limited by minimising the inventory of hazardous materials. However, limitation of inventory is but a particular example of the general principle of designing a plant or process so that it is inherently safer. This approach, to try to eliminate the hazard at source in a cost effective way, may in some cases require new technology but can often be achieved using established methods.

67 Limitation of inventory may be achieved in various ways. One of the most important is to improve the design of the chemical reaction stage. A notable instance is the development of the nitroglycerine process, where the reaction is now carried out in a nozzle rather than a batch vessel with consequent reduction of inventory from about one tonne to a few kilograms. Better reactor design may also lead to reduction of inventory in the 'downstream' processing units. Limitation of inventory can be achieved also in other plant units by better engineering. Some very large reductions of inventory in distillation columns have been described. Other areas where inventory may be reduced include holdup vessels and pipe runs.

68 We consider it should be a specific design objective for a major hazard plant to make it inherently safer. This is the classic route to ultimate safety. It is the direction in which the designer should always aim. The evidence of recent years is that if a company makes inherently safer design an explicit objective and there is a real effort to achieve it, designers are able to respond to the challenge and to effect improvements which are sometimes quite dramatic.

69 Substitution of a more hazardous by a less hazardous process route or material is perhaps the most fundamental approach to inherently safer design. An illustration is the substitution of water for kerosene as the coolant in the process for the oxidation of ethylene. It has been suggested that heat transfer media in general offer considerable scope for the use of substitutes.

70 The principle of inherently safer design may be applied to other aspects of the design of items of plant. An example is the avoidance of large branches on vessels through which hazardous materials can escape and flash off. Another is the design of plant to withstand full explosion pressure as a means of avoiding complex pressure relief systems. Frequently plants are rendered less safe by the introduction of complexity. Important causes of complexity include aiming at an excessive degree of equipment flexibility and making *ad hoc* modifications which in turn require further modifications so that escalation occurs.

71 The above examples by no means exhaust the contribution of inherently safer design, but we think they are sufficient to demonstrate its importance.

High reliability plant

72 Having reduced the scale of the hazard, it is then necessary to complement this by reducing the frequency of realisation of the hazard. This is, in effect, improving the reliability of plant by both technical and managerial means.

73 On the technical side advances continue to be made in many areas which are relevant to plant reliability.[13] They include:

(a) The production and selection of construction materials which are most suitable for the containment of hazardous substances. Improvements lie in the resistance of the materials to corrosion, to mechanical erosion, to deterioration brought about by mechanical or thermal cyclic loading and to propagation of faults in the metallurgical structure.

(b) The design of vessels and pipework to minimise the effect of these sources of deterioration, to reduce stress concentration and to facilitate inspection after construction and in service.

(c) Techniques of non-destructive testing of completed vessels and pipelines and supporting structures for use on completion of construction and throughout the service life.

(d) Techniques of condition monitoring for the continuous observation of pressurised vessels and pipelines and of rotating machinery so that an early warning of actual deterioration is obtained.[14]

(e) Techniques of fracture mechanics which assist in avoiding catastrophic failure.

(f) The instrumentation and control of the plant, a principal purpose of which is to prevent deviations from the design operating conditions and to detect and rectify those which do occur. The effectiveness of such systems has been greatly enhanced by the advent of computer control.

74 The monitoring techniques described highlight the general problem of unrevealed failure which occurs both in plant vessels and equipment, and in instrumentation. In some cases the device is an active one so that failure is immediately obvious because it is no longer performing its function; but in others the device is passive so that failure tends to remain undiscovered. Typically such devices are used for protection. Often they are very simple items such as a tank vent. If there is no system of inspection and repair, the probability that the device will perform satisfactorily when a demand is made on it at some future time tends to zero. A proper appreciation of unrevealed failure in all its aspects and of the need for inspection, is of prime importance on major hazard plants.

75 Allowance should be made in the plant design for human error in its operation. There appears to be a growing consensus both in engineering and in law that the engineer is not entitled to assume that there will be no such errors. We agree with this view. The design should seek both to reduce the frequency with which initial errors occur and to minimise the consequences of such errors by eliminating direct pathways from operator error to major accident. In particular, the design of control systems should take account of the principles of ergonomics to minimise the possibility of human error.

76 We note with approval the examples we have been told about in which managerial control is being improved by modern management techniques and methods of communication, together with the recognition of safety as an essential management function. Areas of management in which advances are being made include:

(a) the direction of design through techniques of hazard analysis whereby sources of hazard in proposed plant are systematically identified and assessed;

(b) the control of materials of construction through quality assurance procedures;

(c) the supervision of construction;

(d) the inspection and testing of the completed construction and the conduct of commissioning trials;

(e) operation of the plant within the design limits aided by the instrumentation and controls provided;

(f) the training of process operators, particularly in fault diagnosis and handling[15];

(g) the detection of deviations from normal operation and of abnormal occurrences, their reporting, analysis and feedback;

(h) the use of the condition monitoring facilities and inspection of techniques available;

(j) the control of modifications to the plant or the process;

(k) the systematic application of maintenance procedures, and

(l) the application of the principles of ergonomics to the design of control rooms and control systems to avoid confusion such as that which occurred at Three Mile Island.

77 Common to both the technical and managerial aspects of control is the need to have a system which ensures that adequate health and safety requirements are maintained at all times. It is not unusual for mistakes at one stage to cause accidents at another. There is for example evidence that errors in design or construction may be a more significant cause of serious incidents than has so far been appreciated. The concept of quality assurance in the broad sense has already been adopted in some industries to maintain the required standard through the stages of design, construction, commissioning and operation including inspection and maintenance. We would endorse this overall approach to aspects of health and safety.

Learning from warnings

78 Even after all reasonable steps have been taken to reduce hazards and risks there may well be several events during the operating life of a major hazard plant which, whilst not resulting in a major accident, could be regarded as potentially dangerous[16]. These precursors may be described in general as 'warning events' or in the most serious cases as 'near misses'. There is much which can be learned from such events. It is essential that there should be an 'in-house' system for reporting and investigating them and for making sure that the lessons are learned and applied.

79 The value of such warnings may well be enhanced by analysis of the hazard warning structure of the plant. Generally the occurrence of a major accident requires the malfunction of more than one preventive feature. The structure of a major accident is often analysed at the design stage using a fault tree which shows the combinations of events which must occur for the top event, i.e. 'the accident', to occur. A fault tree may be used qualitatively to determine the fault paths which can lead to the accident and quantitatively to estimate the frequency of the top event. A fault tree can be constructed in such a way as to make explicit the preventive features which must fail for the major accident to occur, thus constituting a 'hazard warning tree', which might be used to gain greater understanding of warning events. The hazard warning concept is still undeveloped but we believe it may have value at least used qualitatively as an additional tool in hazard control and recommend that industry and the HSE explore its potential.

5 Mitigation

80 As we have already said, absolute safety in any sphere of human endeavour is impossible and it would be imprudent not to take account of the possibility of a major accident, however remote. Where there is a potential for such an accident, mitigating measures can be taken to reduce the impact upon people outside the installation. Firstly, common sense suggests that it is wise, if possible, to keep major hazard plants away from centres of population; similarly, it is wise to avoid a substantial growth in population near an existing installation. Secondly, the effects of any major accidents which do occur can be lessened by putting into action previously prepared emergency plans. These should enable the companies, the local authorities and the emergency services to cooperate efficiently for the protection of the public.

Separation distances

81 The separation distance between a hazardous installation and the public is a planning decision in those cases where a planning permission is required, and as such is not exclusively a technical matter. Planning decisions are discussed in more detail in Section 6. Consideration is limited here to technical guidelines which can be developed to assist the planning authority to make such decisions. However, before considering technical guidelines, it should be clearly stated that, in practice, separation between hazard and public is not a perfect solution to the problem because it has a number of limitations and drawbacks. It affords no additional protection to the workforce, the environment or the plant, it is difficult to specify with any precision; it may be expensive to provide, and it may be a contentious issue between the company, the local authorities and the HSE. In particular for established hazardous installations the risks from a well-run plant would not usually justify imposing a separation distance at the expense of either reducing the activity at the plant or of removing nearby buildings. Nevertheless, the planning process should provide the controls to prevent such situations intensifying or worsening.

82 Ideally, the separation should be such that the population would be unaffected whatever accident occurs. For hazardous installations, however, such a policy is not reasonably practicable. It seems reasonable to aim for a separation which gives almost complete protection for lesser and more probable accidents, and worthwhile protection for major but less probable accidents.

83 A particularly difficult problem is posed by accidents involving drifting vapour clouds. Theoretically a large escape of toxic gas could produce lethal concentrations in places many miles from the point of release. To achieve a low level of risk, separation distances would have to be excessive and for this reason plant reliability must be exceptionally high.

84 The separation of a hazard from a built-up area need not mean, however, that the intervening land is completely sterilised or available only for agricultural purposes. Depending on the degree of hazard, it may be possible for it to be allocated for other purposes involving low population densities, including some industrial developments.

85 In 1972 the DoE and Scottish and Welsh Offices issued Circulars drawing the attention of local authorities to the existence of major hazard plants and giving a list of inventories for various substances which was a precursor of that given in our own proposals for notification[17]. The local planning authorities were invited to seek technical advice from HM Factory Inspectorate (later HSE) when considering the siting of new installations or developments near existing installations. Since then the HSE has dealt with numerous requests for advice from local planning authorities.

86 The decision in any particular case depends not only on the plant itself but also, for nearby developments, on the nature of that development. This is because different developments involve people in greater or lesser numbers and for varying periods of time. Different activities also involve different people of varying degrees of vulnerability. A relatively active and disciplined factory work force for example could reasonably be expected to take cover or evacuate a danger area in an orderly fashion. It would not be reasonable to expect the same response from an old people's home, an infant school or a crowd of shoppers at a supermarket.

87 In spite of the difficulties noted above, we believe that the production and publication of guidelines for deciding the separation of major hazards from people would be of benefit to all parties involved and we understand that HSE are developing such advice for planning authorities. We therefore recommend that the HSE develop and publish their guidelines and include the technical considerations. In making this recommendation we expect that these guidelines will be interpreted and applied with some flexibility. We understand that in the meantime, the HSE will propose consultation distances, based on cautious assumptions, to provide a starting point for the

assessments required to determine specific separation distances for individual cases.

Emergency planning

88 Our main concern here is with off-site emergency planning. The Chemical Industries Association (CIA) has published a guide *Recommended Procedures for Handling Major Emergencies*[18], which concentrates on guidance for action within the site. We consider this provides adequate guidance; our remaining concern is whether its recommendations are followed by plant operators, but this is of course a matter for HSE and CIA.

89 The responsibility for off-site emergency planning lies with the local authorities. In an emergency it is the emergency services, i.e. police, fire brigade and ambulance services, who control the action along the lines of a coordinated plan to deal with such a situation. Industry should provide any necessary information and support to local authorities and the emergency services.

90 Until recently there has been no specific legal requirement in the UK for emergency planning for major hazard plants, although it might be regarded as one of the measures which should be taken to safeguard the public under Section 3 of the HSW Act. However the Directive does contain a requirement for emergency planning and this will be reflected in the UK legislation implementing the Directive.

91 The Directive requires operators of specified installations to prepare an emergency plan for the site. These operators will also be required to pass information on to an appropriate competent authority to enable it to prepare an emergency plan for action outside the establishment. Further, persons liable to be affected by a major accident in a specified installation should be informed of "the safety measures and the correct behaviour to adopt in the event of an accident".

92 HSC issued a Consultative Document[6] in 1983 on the proposals to implement the Directive. The HSE will be the enforcing authority and local authorities are proposed as the competent authority to draw up the off-site emergency plans. We note that the proposed statutory requirements for emergency planning will only apply to installations specified in the Directive and will not be extended down to 'notifiable' installations (i.e. notifiable under The NIHHS Regulations) and we support this.

93 In view of these forthcoming legislative changes both local authorities and industry need to review their approach to emergency planning, in particular in relation to the off-site aspects of an incident at a major hazard plant, which we feel may have been, in many cases, insufficiently appreciated.

94 One of our working groups has held meetings with those involved in emergency planning from government, local authorities, emergency services and industry. It appears that the present level of preparedness for an emergency arising from a major hazard installation varies very much from county to county.

95 We consider there should be a statutory unified system of emergency planning with the responsibilities placed on the local authorities (at county level). They should plan for emergencies which could arise at major hazard plants, both process and storage installations.

96 As far as industry is concerned, implementation of the Directive will create a statutory requirement for emergency planning for specified installations. We interpret this to mean that industry is responsible for on-site emergency planning and that the local authorities are responsible off-site.

97 We consider that industry's role in off-site aspects of an emergency should involve plant operators in providing information, advice and where appropriate supportive action, but not in executive action off-site. We think that the emergency plans of individual companies should be properly coordinated among themselves where they are in close proximity and with that of the appropriate local authorities. To achieve this, it is essential that the plan be discussed and periodically rehearsed with the local authorities and the emergency services.

98 We believe that industry should prepare appropriate models of major incidents and suggested emergency actions which can be used to develop broad-based advice on appropriate measures for local authorities and the emergency services. The form this advice takes and the way in which it is communicated are both important. A range of models covering incidents of escape and dispersion of flammable and toxic materials of graded severity should be considered, but the main effort should be concentrated on those which are serious but not excessively improbable. We consider that on the basis of these studies industry should offer information to local authorities and the emergency services. This information may need to incorporate some different courses of action for different situations, but at the same time it should avoid an excessive number of permutations of possible events and choices.

99 In any emergency, control off-site is the responsibility of the police. A crucial decision which they have to take on the basis of among other things, industry's information is whether to initiate evacuation. We urge that industry should provide, in advance, advice based on the studies described.

100 We believe that there must be clearly defined responsibilities and that liaison personnel should be nominated by companies, from whom information should be available at all times (including a company's silent hours). They should be able to interpret industry's previously provided information in the particular circumstances of an incident occurring. Consideration should be given to nominating someone specifically to liaise with the emergency services and

media during an emergency, leaving those responsible for bringing an incident under control to get on with that job. However, if this type of arrangement is to work effectively then a good communications system is crucial to allow essential personnel to remain in contact during an emergency.

101 We recommend that the CIA should be asked to publish an extension to its code mentioned in para 88 covering industry's role in emergency planning off-site. This could be in the form of a supplement to the existing code or a separate code. In our discussions with the CIA we pressed for the production of such a code and have indicated the general concepts on which we think it should be based.

102 For local authorities, we recommend that there should be a statutory requirement for the preparation of emergency plans for major hazard plants which we think should logically be part of a unified system of emergency planning.

103 The Home Office should consider the revision of the joint Circular ES7/1975[19] which gives guidance to local authorities on civil emergencies, to take account of these developments. We also think that consideration should be given to combining revision of this Circular as far as major hazard installations are concerned with proposals for the administrative arrangements necessary to implement the Directive's off-site emergency planning requirements.

104 We have had described to us a number of systems of emergency planning for industrial hazards. These include the Central Electricity Generating Board's emergency plans for its nuclear power stations and the emergency planning arrangements on Teesside, Canvey, South Humberside and at Fawley. This and other evidence which we have heard indicates that there are in some areas well prepared, effective and tested emergency plans. However, there remain many authorities who do not have adequate plans and still more who do not adequately test the plans they have. As in so many of the other aspects which we have considered, we think that immense progress would be made if emergency planning in all areas could be brought up to the level of the best.

105 We also suggest that the local authorities should consider taking the lead in the creation of local liaison committees which involve themselves, the emergency services and industry as well as the HSE.

106 Usually major incidents arise from escapes of either flammable or toxic material. There is a variety of substances handled by industry where the appropriate responses, antidotes and treatments may well be specific to the particular substance. We wish to emphasise how important we believe it to be that the medical services be prepared to deal with the toxic hazards which exist in their area. We recommend that the Medical Division of HSE should be active in pursuing this objective.

107 Thus although we have supported the view that the statutory requirements for emergency planning by industry should be limited to installations subject to the Directive's implementing legislation, we consider that the emergency planning systems so created will in fact provide a framework for emergency planning for installations down to and below the notifiable level. We attach much importance to this.

108 By the above means, it is hoped that a more uniform and better level of preparedness for emergency situations arising from hazardous installations can be achieved.

6 Planning

109 Control of the location of new developments is the responsibility of local planning authorities under the Town and Country Planning Act 1971 (TCP Act). Government circulars issued in 1972[17] advised local planning authorities to consult HM Factory Inspectorate (now HSE) on planning applications for all new major hazard installations and also on proposals for other development in the vicinity of existing installations. This was to try to ensure that local planning authorities would have the benefit of the HSE's advice on safety aspects when considering planning applications both for the installations themselves and developments nearby. Since 1972 these arrangements have been refined and also now apply to all installations notifiable under the NIHHS Regulations. This section reviews the situation.*

110 Planning law is designed to control 'development' and the overall use of buildings or land, but not specific activities which might take place as a part of that use. Thus, for example, once permission has been granted for a particular use which involves a hazardous substance, an increase in the quantity kept at the installation as part of that use will not attract further planning controls, unless the increase is accompanied by development of the land within the meaning of the TCP Act. This and other loopholes were identified in our Second Report and we made recommendations for changes to planning legislation. These matters are referred to in greater detail later in this section.

111 Decisions where safety is involved often present a dilemma for planning authorities. In many cases the authorities have to weigh the advantages which the proposed development might bring against the disadvantage that more people might be at some risk. The decision is less difficult when this risk is very great or very small, but many cases fall between these extremes. In some cases the decision could mean refusing planning permission for a development which would have brought more jobs to the area in order to safeguard those already living in the area against a marginal increase in risk. It has been suggested that when safety is involved the planning decision should in effect be taken by the HSE on the grounds that planning authorities are not experts in the assessment of risk. We have rejected this in the past and continue to do so as we believe it is based on a misunderstanding of planning principles. When a planning application is being considered a balanced view should be taken of all aspects including social and economic factors and not just health and safety. Our view is that HSE ought to provide a clear assessment of the risks associated with the development and to ensure that plant standards are appropriate for those risks. The decision on whether or not to grant planning permission for an installation which meets health and safety criteria should however rest with the local planning authority who, on behalf of the local community, attempts to come to a balanced decision, having taken all the factors into consideration. In some cases where an installation is of wider regional or national significance, the final decision may be taken by the central government.

112 Planning applications are decided on an individual basis but within the broad policy framework established by structure and local plans. When such plans were drawn up in the past, many local planning authorities had little information or advice about the special needs and problems brought about by hazardous installations. Consequently HSE could be obliged to advise against giving planning consent for general industrial development or against applications for residential development in areas which have been designated for these purposes because they would be too close to an existing hazardous installation. If local plans were prepared with such installations in mind, guidance to developers including industrial developers and the public would be considerably improved. With the notification procedures under the NIHHS Regulations local planning authorities will be able to revise local plans to take into account land use implications of such installations.

113 The 1972 government circulars asked planning authorities to consult HMFI (now HSE) on applications for development in the vicinity of certain installations but there was no explanation of the term 'vicinity'. To be helpful HMFI suggested that it should be taken as meaning a zone of 2 km radius around an installation. Such a general definition was soon to be found unsatisfactory, especially within existing built-up areas, since HMFI had no comment to make on a large number of applications forwarded as part of the consultation process. The result was that some local planning authorities established their own consultation criteria and as a consequence inconsistencies arose. Experience has shown that consultation criteria should be as precise as is practicable in order to avoid unnecessary work for HSE and the authorities. New arrangements introduced in 1983 will greatly improve the understanding and cooperation of all involved. On

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* Throughout this Report all references are to the Acts and Statutory Instruments applicable in England and Wales. The relevant Scottish Acts and Statutory Instruments, while separate, are for practical purposes identical and the views expressed by us apply to Scotland as to England and Wales.

receiving a notification, HSE passes details to the planning authority, and at the same time suggests a consultation zone within which the planning authority is asked to refer certain applications to HSE for advice. The basis of that advice is referred to in Appendix 11. We understand that these arrangements will be explained in the forthcoming revision of the government circulars which will also describe the types of application in which HSE is particularly interested.

114 We consider it essential that local planning authorities should fully understand the weight to be attached to the HSE advice, and that discussions should take place between all interested parties to identify and resolve any difficulties or problems.

Legislative changes

115 In our Second Report we considered whether planning legislation could provide an effective means of controlling a hazardous development. We outlined some weaknesses and made recommendations for changes. Our objective was to ensure that specific planning permission would always be required for a proposed notifiable installation whether entirely new or simply a change at an existing site. We recognise that this objective would not be met unless alterations were made in both the TCP Act and in subordinate legislation (the Town and Country Planning (Use Classes) Order 1972 and the Town and Country Planning General Development Order 1977). Ministers have prepared changes to subordinate legislation which are intended to come into force on 1 May 1984 but we understand that there is no immediate prospect of amending the Act itself.

116 Failure to amend the definition of development in the TCP Act will mean that the creation of a notifiable installation will still not necessarily of itself require planning permission. In such circumstances permission will only be required where some external physical changes are proposed or there is a material change of use (in other words development). Amendment of the two Orders will not fully resolve the issue.

117 It is not possible to estimate how many additional cases would be caught by the proposed changes, nor how many cases would still escape the need to obtain planning consent. There will undoubtedly be a number, some of which could be of significance, the most obvious category being the storage of hazardous materials in existing warehouses. Another category would be where there is an increase of inventory of a hazardous substance being used in an existing factory building, e.g. a change from 15 to 30 tonnes of LPG. The installation would become notifiable but planning permission would not be required unless there were a material change in the use of the land or there were to be external physical changes (i.e. development).

118 We again urge that further consideration be given to the amendment of the TCP Act at the first possible opportunity to close the significant loophole in planning controls for notifiable installations.

119 In our First Report we recommended that planning authorities should be required by statute to consult HSE on planning applications for both notifiable installations and proposals for development in their vicinity. The changes to subordinate legislation (referred to in para 115) will achieve this for new installations in England and Wales (Scotland has had this arrangement since 1981). For developments in the vicinity of hazardous installations we recommended statutory consultation also in the belief that it would be possible to devise arrangements sufficiently flexible to allow selectivity and ensure that unnecessary consultation would not take place. However, it has not proved possible to combine the statutory approach with the need for flexibility in the detailed operation of the consultation arrangements, and non-statutory arrangements have therefore been introduced. We recommend that their effectiveness should be kept under review.

Compensation

120 In our Second Report we outlined the circumstances in which local planning authorities might be liable to pay compensation to developers, and noted that in those circumstances it is local planning authorities alone who have to bear the financial burden for decisions taken in the interests of public safety. We recommended then that the Secretary of State for the Environment review the extent of his discretionary powers to make payments to local authorities to meet compensation liabilities.

121 We feel obliged to return to the matter of compensation as we consider it could have considerable implications for safety. DoE's present proposals for planning changes could create a right to compensation in those cases in which a developer's existing planning rights are withdrawn. We are of the opinion that these financial considerations might in some circumstances deter local planning authorities from making decisions in the best interests of the safety of the community. We therefore recommend that the Secretary of State for the Environment give further consideration to present compensation arrangements.

7 Education

122 The educational requirements for engineers working in the major hazard area are essentially the same as those in other areas, except that if the needs are not properly met, the consequences may be much more serious.

123 The right philosophical approach is for senior management to insist that staff receive adequate training and adopt a reasonable approach to the safe design and operation of plant in which hazardous materials are processed. A systematic approach towards loss prevention has developed considerably in the last decade or so and it is only during this period that the subject has received satisfactory treatment in undergraduate, postgraduate and post-experience courses. As a result senior staff, who fulfil key roles in the area, may not have had the advantages of these educational opportunities and it is therefore important that suitable courses should be available to supplement their experience. It has always been the view of the committee that an enlightened attitude towards safety in senior management is the key to establishing the appropriate climate throughout the whole organisation.

124 It is important that students be introduced to the concept of inherently safer design and that they realise that safety in plant operation must be considered right at the start of the design study. Process safety must be taught in a rigorous, stimulating way by staff of appropriate experience. Departments which initially do not have this expertise may need to use the services of experts from other universities, industry and consulting firms. By virtue of the nature of the processes which give rise to major hazards, it is the chemical engineer who often fills the position of responsible person in the design or operation of plant. It is pleasing therefore to note that there has been a progressive strengthening of process safety in the essential core material, *A Scheme for a Degree Course in Chemical Engineering,* produced by the Institution of Chemical Engineers. All university and polytechnic courses which give exemption from the examination requirements for corporate membership of the Institution, and hence for Chartered Engineer status, must cover the syllabus, but the extent to which this is done by formal lectures or as part of the design project is left to individual universities.

125 Universities have an important function in postgraduate training and research and it is apparent that an increasing number of Departments of Chemical Engineering are working, frequently in collaboration with industry, in areas related to process safety including reliability engineering, modelling and assessment of hazards. Two specialist departments — Fire Safety Engineering at Edinburgh and Occupational Health and Safety at Aston — are doing valuable work and we consider it important that their futures should be secure. Courses are frequently organised on a modular basis so that individual modules may be taken by engineers from industry.

126 On leaving university, students should have an understanding of basic principles and techniques relating to safety and an attitude of mind which makes them receptive to the need for further training. The Institution of Chemical Engineers has assisted in this by the stimulation and coordination of courses in which universities, industry and consultants have all played important parts, and by the production of its *Loss Prevention Bulletin.* It is regrettable that a fall-off in attendance at these courses has occurred recently, no doubt partly due to a reluctance of industry to release key personnel for other than short courses. There is a similar situation with other post-experience safety courses.

127 We think it is shortsighted policy today to ignore these opportunities for further training. We consider that this situation is of concern since a lack of appropriate safety training in the short term will contribute problems in the future. We therefore recommend that industry should be willing to release staff at all appropriate grades up to senior level to attend courses specifically aimed at improving their safety awareness and performance. We further recommend that there should be more short courses available and that the longer courses should have a modular structure. A strong plea is made for government finance to be made available to cover the cost of such courses.

128 Engineers, other than chemical engineers, and scientists, including chemists, physicists and biologists, may be the key responsible persons for some processes and plants, in which case they will require a similar understanding of safety principles. It is recommended that other professional institutions, where appropriate, should follow the example set by the Institution of Chemical Engineers.

8 Research

129 We described in the previous section the important role of education in ensuring awareness of current standards in major hazard control. We now consider the role of research to help improve standards. We drew attention in our Second Report to the importance we attach to research, and in this section and the appendices we discuss the subject in greater detail. From an improved understanding of the mechanisms of plant failure, better standards of plant design and control should result so that the risk of failure is reduced. While this must be the first objective in major hazards research, there is also a need to study the consequences of a large scale release of a flammable or toxic substance if for some reason there is a loss of plant integrity, and how these consequences can be mitigated.

130 Considerable effort has been put into research over the past few years, both nationally and internationally, and we note particularly the valuable cooperation between researchers in this field. We consider it of great importance that organisations which are carrying out research relevant to major hazards maintain a liberal policy in relation to the publication of results and keep in close contact with other organisations working in their area of research to minimise overlap and make the most rapid overall progress.

131 We have continued in our task of trying to identify areas where further work is required. To assist in this we have considered it important to visit organisations in the UK which are carrying out valuable research on major hazards. Thus we have had discussions with Shell Research, British Gas, Imperial Chemical Industries, Department of Trade and Industry (Warren Springs Laboratory) and HSE, and we have received much useful information about current work, and proposals for future research. In this section we look at the subject as a whole and in Appendices 5–10 and 12–14 specific areas of research are discussed in greater detail. It will be noted that some of these appendices have been prepared by HSE staff at our request. The HSE itself is a major contributor to research over a wide range of major hazard topics through its own research laboratories and through research contracted to other bodies, particularly the Safety and Reliability Directorate of the United Kingdom Atomic Energy Authority. Much of this work has also been published.

132 We are concerned above all with loss of containment. While we recognise that ultimately any failure of a man-made system can be regarded, in a sense, as a human failure, the immediate cause of such an event may arise from a failure of hardware or from direct human error. It is convenient therefore to review research on hardware and human reliability separately but we must recognise the importance of the interrelationship between the two. The avoidance of loss of containment depends in large measure on plant reliability. This is too large and disparate a field for us to make detailed recommendations, but we have indicated, particularly in Section 4, some aspects which we think important. In particular, we wish to express support for research on major hazard plant design.

133 Another important aspect of hazard control is the regular inspection of plant, especially the relief systems and controls. This inspection may take the form of a simple visual check, but condition monitoring is becoming a sophisticated tool of considerable value and further effort should be devoted to its development. There is clearly a need for further development of techniques for in-service monitoring of such effects as corrosion, erosion, fatigue, mechanical damage and incipient leakage in systems of containment. Ideally, these would be on-line and continuous but, for a start, there is room for progress in inspection techniques. Examples of progress to date are the 'intelligent pig' for pipelines and techniques for acoustic monitoring now emerging for pipeline and vessels.

134 While the role of man in the safety aspects of industrial systems is increasingly appreciated, we consider that research into human reliability, and its subsequent application, still tends to be fragmented and applied narrowly to specific tasks and industries. Any assessment of the behaviour of individuals at work is bound to be complex but if reliable quantitative techniques are to be established efforts must be directed towards establishing reasonable bases of fact and assumption. A paper on this subject is presented at Appendix 13 and we support the view that some mechanism should be set up in this country to review and give guidance on research in this field.

135 Reliability improvement and reliability assessment are linked. We think there is need for work which establishes more clearly the dependability of fault tree assessments and the level of reliability which is feasible in plant design. These aspects are discussed in Appendix 12.

136 If a failure of primary containment does occur the consequences of the release of a significant quantity of hazardous material depend on a number of complex factors, including the nature of the material,

the conditions under which it is held and the type of environment which surrounds the plant. Research has tended to fall into two parts; the evaluation of the source term, which defines the physical form of the emission as well as the rate of emission, and the examination of the consequences of the release. While such research usually has industrial storage and process in mind, its application to the transport of hazardous materials is also highly relevant.

137 A short review of research on emission is given in Appendix 5 and there would appear to be two particular areas for future work. There is a need for better information on the behaviour of flashing jets and on atmospheric entrainment into them. There should be further study of the spread and evaporation of pools of cryogenic and non-cryogenic liquids on land and water. While these proposals are mainly concerned with a breach of primary containment, there is also a continuing need for research on the effectiveness of secondary containment, such as bunds, ducts or catchment pits, or buildings.

138 Some of the major releases of hazardous material can lead to the formation of clouds which are heavier than air and a review of the present position on heavy gas dispersion is given in Appendix 6. Since our Second Report, a number of large-scale trials have been undertaken in order to simulate what might occur in current industrial operations. Such trials are very expensive and time-consuming. They involve expenditure of several millions of pounds, and much credit must be given to those who have recently funded and carried out valuable experimental work in the UK such as at Thorney Island and before that at Maplin Sands[20].

139 Because of the complex nature of the problem of dispersion, initial work has nearly always considered the simplest situation, a release of heavy gas over flat, open and uniform terrain. Once the mechanisms of turbulence and dispersion under these conditions have been reasonably established, the next stage is the examination of the effects of obstructions and features such as ground slope. The second part of the Thorney Island trials has been concerned with the effect of structures such as walls and buildings. Another critical area for future research is establishing how a release of hazardous material is likely to occur and how it will form a gas cloud in close proximity to the point of escape. Such work is closely related to the research on emission which we have discussed earlier in this section. We have also referred to the enormous cost of large scale experimentation. We strongly support the view that every effort must be made to extract the maximum information from wind tunnels and any other cost-effective small scale experimentation.

140 One of the serious consequences of the release of a large quantity of volatile flammable liquids or flammable gases is that subsequent ignition may lead to an unconfined, or partially confined vapour cloud explosion, the type of event which produced such disastrous effects at Flixborough. Research on this topic is discussed in Appendix 7 and we also draw attention to a recent paper by M J Pikaar[21]. It is only in the last few years that some of the difficulties in this area of research are being surmounted and there is now a prospect of being able to explain or predict the circumstances which can give rise to a vapour cloud explosion and what the effects are likely to be. Further research is important in this regard particularly to create understanding on how flames can be accelerated to the point where appreciable overpressures are generated, the simulation of non-spherical explosions, and the effect of blast on structures.

141 Another possible consequence of the rapid release of a large quantity of volatile flammable material is the phenomenon known as a fireball, which is described in Appendix 8. In this event ignition takes place near the source of the escape so that burning and mixing take place together. At present, estimates of the thermal effects are based on the results of small scale experimentation and empirical calculations and the technical and financial needs of large scale work to validate or improve these conclusions should be determined with a view to promoting a collaborative research programme.

142 The effects of toxic substances are almost as varied as the toxic chemicals which might be released and we have discussed in Section 3 the problems associated with the recognition and the assessment of toxic hazards. There is a need for a better system of identifying the toxic substances which could have the potential under particular conditions of use to cause a major accident. We understand that there is research being undertaken in this area.

143 The objective of all work on the control of major hazards, including research, is to reduce the number of human casualties by reducing the probability of a release occurring and by mitigating the consequences of any release. However, while methods for the calculation of physical phenomena improve, many effects of these phenomena on people are still known only in very general terms. We have already referred to problems in estimating the effects of fires, explosions and the release of toxic substances on the surrounding population. We see this as the area where further research is needed so that a better idea may be obtained of the possible number of casualties arising from any particular incident scenario.

144 Our review strongly highlights the need to obtain as much scientific information as possible from actual incidents when they occur. The data potentially available from large incidents gives rise to serious effects of a kind which in practice no experimental work could ever provide. We therefore, emphasise the need for satisfactory systems for the collection, storage and retrieval of data. Various types of information systems are required, recording data on equipment failure and repair, on human error and on accidents and incidents. Furthermore, any assumptions made in the interpretation of evidence need to be formally listed. The modern approach to such problems is to

create computer data bases which may be searched rapidly by associated information retrieval programmes and this is discussed in Appendix 14.

145 We are also concerned that the present standards of reporting incidents vary almost as widely as the incidents themselves. We see a need for an improved system of classification of major incidents on hazardous installations. There is no doubt that an agreed standard of reporting incidents would greatly enhance the quality of the information which is available and this would be of great benefit both nationally and internationally[22]. This aspect is considered in more detail in Appendix 12.

9 Conclusions and recommendations

Transport

146 We recommend that the major hazard aspects of the transport of dangerous substances should be pursued (para 11 and Appendix 2).

Living with risk

147 We believe that the "reasonably practicable" approach embodied in the HSW Act is applicable to the control of major hazards and should continue to be followed (para 15).

148 We believe that there are upper and lower limits between which risks and benefits need to be balanced but that there is less scope for setting a risk criterion than is sometimes acknowledged (paras 19 and 20).

149 We believe that there is widespread support for the following propositions.

(a) The risk from a hazardous installation to an individual employee or member of the public should not be significant when compared with other risks to which he is exposed in everyday life.

(b) The risk from any hazardous installation should, whenever reasonably practicable, be reduced.

(c) Where there is a risk from a hazardous installation, additional hazardous developments should not add significantly to the existing risk.

(d) If the possible harm from an incident is high, the risk that the incident might actually happen should be made very low indeed (para 21).

Information to the public

150 We think that the information given to the public nearby should include:

(a) the nature of the hazards which might affect them if control measures fail;

(b) the emergency arrangements which have been made in advance, and

(c) what they should do in a major incident (para 23).

151 We believe that there should be informed debate about major hazards and that there is need for the dissemination of some information which goes beyond that required by the Directive (paras 29 and 33).

152 We recommend:

(a) Unless responses to the HSC Consultative Document suggest otherwise, local authorities and local industry should devise systems to provide information to those members of the public likely to be affected by major accidents, in accordance with the requirements of the Directive.

(b) The information requirement of the Directive should be applied to notifiable installations when HSE thinks it appropriate to do so.

(c) Local liaison committees should be set up for notifiable installations, where appropriate, to bring together the public, industry, the emergency services and the HSE.

(d) Voluntary arrangements for the supply of information to the public which go beyond what is needed for emergencies under the Directive should be extended and encouraged by trade associations.

(e) The HSC should re-examine its powers under the HSW Act and consider whether regulations are required to secure the provision of specific information to designated recipients (para 35).

Recognition and assessment

153 We note that there are inconsistencies in the list of substances in Annex III of the Directive (paras 40 and 41).

154 When the Directive is reviewed we recommend strongly that a more practical approach should be adopted and stress that the threshold quantities for some highly toxic substances are far too severe. At our instigation, the HSE has sponsored research to develop guidelines to assess the equivalence of hazard for these and other toxic substances (para 42).

155 We believe that most, if not all, accidents affecting the environment will also affect man, and therefore we believe that measures taken to protect man will for the most part protect the environment. We think the subject should receive further attention some time in the future (para 48).

156 We adhere to our original view that there is at present no case for distinguishing between materials in process and those in storage (paras 49 and 50).

157 We still hold the view that the hazard surveys we recommended in our previous reports should in part be based upon some form of quantitative assessment. We note that the discipline of quantitative assessment is still developing rapidly and is only one useful element in the overall system of control and

only one input to be considered in the decision making on major hazard plants (paras 59 and 64).

158 We believe that the HSE should develop and make known the guidelines of what is good current practice in quantitative assessment (para 63).

Avoidance

159 We attach the highest priority to the avoidance of accidents by inherently safer design, high reliability plant and learning from warnings (para 65).

160 We consider a specific design objective for the major hazard plant should be to make it inherently safer (para 68).

161 We endorse the full use of the technical and managerial techniques available to ensure high plant reliability; measures should be taken to combat unrevealed failure and human error (paras 74, 75 and 77).

162 We believe it is essential that there should be an 'in-house' system for reporting and investigating warning events and for making sure that the lessons are learned and applied (para 78).

163 We recommend that industry and the HSE should explore the potential of the hazard warning concept (para 79).

Mitigation

164 We believe it would be imprudent not to take account of the possibility of a major accident, however remote; the main mitigating measures are to keep major hazard plants away from centres of population and to plan for emergencies (para 80).

165 We believe it is reasonable to aim for a separation (between plant and the public) which gives almost complete protection for lesser and more probable accidents and worthwhile protection for major but less probable accidents (para 82).

166 We recommend that the HSE develop and publish their guidelines and the technical considerations for separation distances (para 87).

167 We believe that the CIA code provides adequate guidance for on-site emergency plans (para 88).

168 We recommend there should be a statutory unified system of (off-site) emergency planning with the responsibilities placed on the local authorities (at county level) (para 102).

169 We believe it is essential that all emergency plans be discussed between industry, the local authorities and the emergency services, and periodically rehearsed (para 97).

170 We recommend that the CIA be asked to publish guidance covering industry's role in emergency planning off-site (para 101).

171 We suggest that the Home Office be asked to consider the revision of its joint Circular ES 7/1975 to take fuller account of major industrial accidents (para 103).

172 We recommend that the HSE should actively pursue the ways in which local medical services should prepare to deal with toxic emergencies in their localities (para 106).

Planning

173 We still believe that the decision on whether or not to grant planning permission for a hazardous installation should continue to rest with the local planning authority (para 111).

174 We believe it essential that local planning authorities should fully understand the weight to be attached to the HSE's advice and that discussions should take place between all interested parties to identify and resolve any difficulties or problems (para 114).

175 We recommend that government departments be asked to give further consideration to the amendment of the Town and Country Planning Act 1971 at the first possible opportunity to close the significant loophole in planning controls for notifiable installations (para 118).

176 We recommend that government departments be asked to give further consideration to present compensation arrangements (paras 120 and 121).

Education

177 We believe that an enlightened attitude towards safety in senior management is the key to establishing the appropriate climate throughout the whole organisation (para 123).

178 We recommend that industry should be willing to release staff to attend courses aimed at improving their safety awareness and performance (para 127).

179 We recommend that there should be more short courses available and that the longer courses should have a modular structure (para 127).

180 We recommend that other professional institutions follow the example of the Institution of Chemical Engineers in the development of safety training (paras 124, 125 and 128).

Research

181 We believe that a great deal of scientific research has been done in the major hazard field and much has been published (paras 130 and 131).

182 We believe that it is of great importance that organisations maintain a liberal policy in relation to the publication of research work (para 130).

183 We support the view that some mechanism should be set up to coordinate research on human reliability (para 134).

184 We believe there is need for further work on:

(a) in-service monitoring and inspection techniques (para 133),

(b) factors affecting the emission of hazardous materials (para 137),

(c) dispersion of heavy gas clouds (para 139),

(d) vapour cloud explosions (para 140),

(e) fireballs (paragraphs 12 and 141),

(f) toxic substances (para 142) and

(g) the effects of major accidents on the surrounding population (para 143).

185 We believe there is need for satisfactory systems for the collection, classification, storage and retrieval of data from incidents (paras 144 and 145).

Glossary

This glossary does not aim to be a dictionary of technical terms. Firstly the terms are restricted in number and secondly it is not intended to define them for general use. We acknowledge that other meanings may be given to these terms in everyday speech, in technical contexts and in industry. The purpose of the glossary is to give the meaning of certain terms as they are used in the report.

At risk see Risk.

Bund, bunding a system of containment for catching liquid spillage. It may take the form of a low wall surrounding the area or a shallow pit, or some combination of the two.

Catastrophic fire see Fire.

Competent authority the Authority set up or appointed by a member state to fulfil the requirements of Article 7 of the Directive.

Condition monitoring surveillance of the condition of plant equipment by visual observation and, more particularly, by instrumentation, on a periodic or continuous basis, in order to obtain early warning of the development of defects or malfunctions.

Cryogenic fluid a gas liquefied by refrigeration at temperatures below those encountered in nature on the earth. Examples are liquefied natural gas and liquid oxygen.

Development a legal term having the meaning "Carrying out of building, engineering, mining or other operations in, on, over, or under land, or the making of any material change in the use of any buildings or other land".

Dioxin dioxin is the common name for 2, 3, 7, 8 — tetrachlorodibenzo-p-dioxin. It was the principal cause of harm in the Seveso disaster in 1976. It is a solid substance which, in minute quantities in contact with the skin, gives rise to the disfiguring disease chloracne. It is highly toxic and extremely persistent.

Domino effect a situation in which a major accident on one site gives rise to consequential accidents on a neighbouring site.

Dust explosion an explosion which results from the ignition of a mixture of finely divided combustible solids and air. The effect of such an explosion is comparable with that which results from the ignition of an equal volume of air mixed with flammable vapour.

Fault tree a diagram which expresses the logical relationship between the combinations of events which lead to an accident. The accident appears as the TOP EVENT of the fault tree.

Fire catastrophic fires are those which are distinguished from fires ordinarily encountered by their intensity, their rapidity of spread or their size, or some combination of these factors.

Hazard a physical situation with a potential for harm to life or limb.

Hazard assessment a formal, systematic appraisal of the nature and magnitude of the hazards associated with an installation.

Individual risk see Risk.

Intelligent pig an inspection device which passes down a pipeline to detect and locate flaws in the pipewall.

Loss prevention an approach to safety in the chemical and process industries distinguished by an emphasis upon incorporating safety into the initial design of plant and equipment.

Major hazard a hazard which has the potential for major harm to employees, the public or the environment.

Notifiable installation an installation which is required to be notified to the HSE under the NIHHS Regulations 1982.

Reliability the probability that an item will perform a required function under stated conditions for a stated period of time.

Risk in the general sense this means the chance that an undesirable or harmful event will take place. It is also used more precisely in quantitative analyses to mean the calculated probability of the realisation of a hazard.

Risk, at subject to a significant probability of harm if a given hazard be realised.

Risk, individual the probability of an individual being harmed as the consequence of a specified hazard.

Risk, societal the probability of a defined number of people being harmed as the consequence of a specified hazard.

Scaling laws laws which relate quantity of hazardous substances to the consequences of the realisation of the hazard.

Societal risk see Risk.

Stress concentration a property of a component under stress whereby stress in some locations has a value many times greater than the mean value.

Top event see Fault tree.

Abbreviations used in main report

CIA	Chemical Industries Association
CIMAH	Control of Industrial Major Accident Hazards Regulations (Draft)
DOE	Department of the Environement
HMFI	Her Majesty's Factory Inspectorate (part of the HSE)
HSC	Health and Safety Commission
HSE	Health and Safety Executive
HSW Act	Health and Safety at Work etc Act 1974
LPG	Liquefied Petroleum Gas
NIHHS Regulations	Notification of Installations Handling Hazardous Substances Regulations 1982

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Appendix 1 Brief outline of the First and Second Reports of the Advisory Committee on Major Hazards

First Report 1976

Nature of the problem. Increase in both industrial plant size and the development pace of related technology has produced a social reaction. The need is demonstrated for the establishment of controls for new industry which balance safety requirements against practical economic factors. HSW Act 1974 provides basis for such a control system. (pages 9–10)

Identifying major hazards and assessing risk. The nature of flammability and toxicity threats. Although the full potential of a hazard was seldom realised the minimisation of risk was necessary. Recognition that complete elimination of plant failure was itself impossible. Consideration of quantitative objectives in risk assessment. (pages 11–13)

Notifiable installations. Outline scheme for notification, survey, assessment and appraisal of various categories of hazardous installations. List of various categories of installation. There was a requirement to submit hazard surveys of plant, procedures and hazard methods to HSE, leading to the possible selection of installations requiring more elaborate risk assessment by a specialist unit. (pages 14–18)

Application of controls to major hazard installations. The role of management seen as the dominant factor insomuch as they must satisfy HSE standards; but control methods should not dilute final managerial responsibility. Discussion of control methods:

Codes of Practice
Licensing Regulations

No new sub-standard installations should be allowed whilst existing installations should be brought up to adequate standards. (pages 19–22)

Planning controls. Hazardous installations siting should be part of general area planning considerations. Case for the formalising of existing HSE/local authority consultative arrangements prior to planning permission decisions. Investigation of control over hazardous process variations not covered by present planning arrangements. Possible effect of restrictive planning controls on compensation claims made to local authorities. The complexity of practical issues involved necessitated further discussion with the Department of Environment. (pages 23–25)

Second Report 1979

The examination of historical experience and the frequency and consequences of major hazard incidents. Data seen as generally supporting the levels at which inventories should be notifiable. Consideration of theoretical prediction techniques. (pages 10–18)

Justification of inventory levels in the proposed schedule of specific substances. Developing thoughts on the survey, assessment and appraisal of various categories of installations led to the definition of priority sites which would need hazard surveys as those with 10 times the notification level of inventory. (pages 19–22)

Evidence of installation operators in defence of existing safety procedures. Consideration of 'Licensing' regulations as further controls and an outline scheme for licensing (Appendix 1). Further discussions intended when proposed notification regulations have been practically evaluated. (pages 23–26)

Hazardous development locations regarded as a matter for planning authorities. Limitations of the present planning controls over the introduction or the increase of hazardous processes at existing installations. Means whereby planning controls may be applied to new sites, intensified activity at existing sites and surrounding area development. Possible effect of restrictive planning controls on compensation claims to local authorities with a suggested Department of Environment response. Practical considerations of siting problems. (pages 27–31)

Recent knowledge on the formation, behaviour and explosion of vapour clouds. Discussion of factors affecting the magnitude and destructive effect of vapour cloud explosions. (pages 32–39)

Discussion of explosive vapour cloud hazard areas and the location, function, design-criteria and siting of management control buildings. Examination of vapour explosions on control buildings at Flixborough and Beek. Flying glass problems. (pages 40–45)

Safety of personnel on site considered as of parallel importance to the consideration of plant and buildings at the planning and design stage. Establishment of categories of people and hazard areas relative to risk, and discussion of the buildings, siting, construction and access limitation within site boundaries. The essential features of formalised procedures and permits in designated areas. (pages 46–48)

Findings of the working group on research. Evaluation of available data to identify areas of continuing concern in the major hazards field. Discussion of heavy gases dispersal problems, related trials and recommendations. Encouragement of collaboration at international, governmental and industrial levels. (pages 49–51)

Identification of areas requiring further committee consideration. (pages 52–53)

Conclusions and recommendations of the Committee.

Notification and inventory
Hazard assessment
Hazard surveys
Legal controls
Planning
Explosion hazards
Site safety (pages 54–55)

Appendix 2 Major Hazard Aspects of Transport: ACMH Report to HSC

Introduction

In June 1981 the Health and Safety Commission asked us to "consider whether there are any aspects of the transport of dangerous substances which have the potential to create a major hazard to employees or to the public or to the environment" and to report back within one year. In response, we formed another Working Group (Group F) with the following members: Professor J L M Morrison (Chairman), S Hope, V C Marshall, Professor J F Richardson, E J Challis* and H E Lewis*. B H Harvey, ACMH Chairman, attended as an *ex-officio* member of the Working Group.

This paper is based upon the discussions of that Group.

We were not required to consider the matter in depth but to make such preliminary enquiries as would establish *prima facie* whether or not further work was called for. In that context therefore, we have talked only with representatives of regulating authorities, and with the exception of British Rail, have approached neither users nor other commercial interests. In one sense our task was simple — if dangerous substances are transported in or above the quantities which the Commission has accepted as appropriate for identifying static major hazard installations then a potential major hazard situation must exist. This applies to quantities which merit notification and more so to quantities which merit hazard surveys. Nevertheless we felt that the Commission would require us to give indications of the particular aspects of the various modes of conveyance which appear to merit further investigations. We also believe that examples of the aspects we have been considering would add substance to our recommendations.

As in the case of static installations we have been concerned to identify possible circumstances in which a major accident involving transportation of dangerous substances could affect non-employees or members of the public as well as the workers directly concerned. Although during a long journey the people at risk are constantly changing and individuals may be only exposed to the hazard for a short time, the total number affected by a quantity of a dangerous substance may be larger than at a factory where it is produced or used. We have examined the principal modes of the bulk transport of hazardous material namely those of sea, rail and road. Pipelines had already been considered by another of our Working Groups and their findings have been reviewed by us and are summarised below. In all these forms of transport quantities of hazardous substance are carried in excess, and in some cases greatly in excess, of the quantities that we recommended should constitute a major hazard threshold for fixed installations. Serious incidents involving the transport of dangerous substances in various parts of the world, (none yet in the UK) confirm the potential hazard that exists. Incidents which have attracted particular attention have been:

(a) At Bantry Bay, Ireland, in June 1979 where fifty people died following a serious leak of oil and an explosion in connection with the unloading of the tank ship *Betelgeuse*.

(b) At Mississauga, Canada, in November 1979 where a freight train of mixed cargo including propane and chlorine derailed with subsequent fire and explosion. Over two hundred thousand people were evacuated because of the toxic hazard from the possible release of chlorine.

(c) At San Carlos, Spain, in July 1978 where a road tanker carrying about 22 tonnes of propylene ruptured near a camp site killing over 200 people in the ensuing conflagration.

(d) At Port Hudson, Missouri, USA, in December 1970 where a pipeline ruptured releasing a considerable quantity of propane which on ignition at a nearby unoccupied farm house led to one of the largest known vapour cloud explosions although no one was killed.

(A summary is given in the Annex of these and some other well known transport accidents which have been taken in part from Chapter 1 of our Second Report.)

It might not be wholly inappropriate to mention at this point three very recent accidents in this country.

(a) At Milford Haven, in December 1981 where the *Hullgate*, a small (3000 tonnes) oil tanker with a cargo of 500 tonnes of petrol, was taking on approximately 7000 litres (1500 gallons) of bunker fuel. An explosion occurred in which one man died and six other crew members were injured. Firemen and dockers fought successfully to keep the ensuing fire from spreading to the petrol. A neighbouring large tanker was safely towed away and no damage was done to any of Milford Haven's four oil refineries, in which however all work was suspended during the emergency. This incident could be regarded perhaps as a 'near miss': on the other hand it could be taken as redounding to the credit of the safety precautions and personnel.

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* Co-opted members

(b) At Gainsborough in September 1981 where 16 tank wagons in a freight train were derailed. Two empty 100 ton g.l.w. wagons that normally carry petroleum spirit were badly damaged and had their tanks ruptured. This accident was potentially serious and was caused by minor track defects and excessive train speed. Also at Seer Green where a passenger train ran into the rear of a stationary train we note from press reports issued at the time that the incident occurred in severe weather conditions and that there appeared to be a lack of communication between the drivers of the train and the signalmen. No doubt these aspects will be part of the considerations of the official inquiry.

I Sea transport

Hazardous substances are transported by sea in quantities which are enormous even in major hazard terms. Bulk carriers carry many times the amount which has now been defined as a major hazard at a static installation. For example, notifiable levels set down in our Second Report for chlorine, ammonia and LPG were 10, 100 and 30 tonnes respectively; whereas ships entering UK ports might carry 2,000, 10,000 and 30,000 tonnes of the same substances. Such ships may penetrate estuaries, harbours and narrow channels to take them through or into large centres of population where other vessels may use some of the same facilities. They are subject to winds, tides and currents: controlling and manoeuvring such large floating structures is inherently difficult. In our reports on land-based installations, we have emphasised the vital role which sound construction and maintenance, together with competent management, must play. Our present, admittedly limited, enquiries into recent incidents do not reassure us that these are universally achieved in relation to shipping. Although the proportion of poor ships and crews may be very small, it has to be remembered that Very Large Crude Carriers alone berth about 300 times annually in this country.

There are national laws and international conventions for the seaworthiness and safe operation of ships but their effectiveness is called into question by incidents such as that at Bantry Bay involving the *Betelgeuse* and at Rotterdam involving the *Energy Concentration.* We have noted, however, the recently introduced Statutory Instrument No. 1077 "Merchant Shipping — The Merchant Shipping (Tankers) (EEC Requirements) Regulations 1981" which came into operation in October 1981 and which, if effective, should help to identify situations where standards and procedures are below the acceptable level.

To minimise the risks of a major hazard disaster there must be clear definitions of the functions of the ship's crew, of the personnel of the shore installation and of the harbour authorities and there must be adequate systems of communication between them. One aspect that has emerged from our enquiries was that transport of dangerous cargoes by sea appears to be the subject of a number of different regimes of control, not only as a vessel moves from the high seas into a port but also because controls regarding design and construction are to some extent separate from controls regarding operation. These factors lead to a very complex situation and we consider that much more time could usefully be spent in determining the interrelationship of the various responsibilities.

For commercial reasons, ships load and discharge their cargo very rapidly and as a consequence the pipes transferring the liquid cargo, flammable or toxic, are as large and the rates of flow are as high as is practical. In the event of a fracture of the loading system, even if the automatic cut-off devices work properly, spillages of the order of tens of tonnes may still occur. In the event of the failure of the cut-off devices spillages may be very much larger.

We are also concerned with the application of planning controls at or near ports or harbours that handle major hazard quantities of hazardous material. We consider that the relevant planning authorities should appreciate the nature of the hazard involved in a way similar to that being evolved for static major hazard installations. We, however, in the time available were unable to pursue this aspect to any extent.

We therefore consider that further study should be undertaken,

(a) to determine the interrelationship of the various regimes of control for vessels carrying major hazard cargoes into ports and harbours;

(b) to review the possible role of hazard analysis for certain operations and in particular stowage, loading and discharging, and

(c) to consider the application of planning controls for developments at and in the vicinity of ports and harbours handling major hazard cargoes.

II Rail transport

This mode of transport provides a complete contrast in that one operator, British Rail, is responsible for the vast majority of the system and handles most if not all the major hazard quantities of hazardous substances. There is also a single regulatory authority, the Railways Inspectorate. Although the carriage of dangerous material (explosive, toxic, or flammable) by rail in quantities comparable with the limits suggested for fixed installations must be regarded as constituting a major hazard, and there is ample evidence as detailed in our Second Report that these hazards can be realised, it is noteworthy that not one of the incidents cited therein occurred in this country. Indeed our discussions with the Railway Inspectorate and British Rail have impressed us with the care taken to avoid accidents and to minimise consequences. Even so, accidents do still occur, due mainly to derailments or occasionally to collisions; but a rate reduced to about one in about 10^8 tonne-miles must be seen as commendable. Still striving for improvement, British Rail have plans for a wide range of projects including the use of computers for the separation of incompatible loads, re-routeing, better communications, improved vehicle construction and the like.

One aspect of rail transport attracted our attention. This was the need to have marshalling or reception yards where freight trains might be held awaiting onward movement. It was clear from the discussions that considerable quantities of hazardous substances could be held at any one time. We considered that for such sites it would not be unreasonable for the operator to undertake the equivalent to a hazard survey if the total quantity was liable to exceed a given amount. We were not clear also as to the extent to which such sites were subject to planning requirements and in particular considered that planning authorities should be required to consult HSE in relation to developments in this vicinity.

Although we understand that considerable improvements have been made in communications facilities between trains and signal staff, we would suggest that good communication is an essential element for the safe movement of major hazard quantities of hazardous substances and particularly in a post accident situation.

We also were concerned about the routeing of hazardous loads. British Rail said that, in general, there was little flexibility available. The Group however considered that when such flexibility existed it should be made use of and felt strongly there should be some control of movements in particular sections of the route, such as long tunnels*, where there might be grounds for imposing some restriction on the simultaneous movement of trains carrying passengers and major hazard quantities of dangerous materials.

III Road

In our Second Report we touched on the major hazard implications of road transport. A very large amount of dangerous material is transported by road. Although the maximum quantity of material likely to be involved in any one accident will be much less than in a shipping or rail incident, considerable quantities are being carried through centres of large population and therefore accidents with serious major hazard consequences could occur at any time. In the UK, the recent introduction of Regulations for Road Tankers (SI 1981 No. 1059) has been noted and should, in our view, improve the controls and lead to a safer system. It must be realised, however, that road transport is unique in that the road system is universal with the result that the opportunity for accidents is widespread and intimate. It is that factor which accounts for public apprehension. Nevertheless, we doubt if any general enquiry into road transport is warranted but a number of matters appear to require further consideration, the most obvious of these are loading and unloading terminals, routeing and intermediate stopping places. The last aspect includes the overnight parking of vehicles which may not only be dangerous in themselves but whose loads may be incompatible with other loads. Parking or staging posts introduce planning problems comparable with those for fixed installations and for sea and rail transport as outlined above.

IV Pipelines

Some of our earlier investigations of pipelines concluded that, while these can be well designed, constructed, and operated, to provide a safe means of transport there is a major hazard threat when certain materials are carried.

This arises from the fact that large quantities of hazardous substances are carried through the public domain and could be released in the event of an accident. The potential threat differs somewhat from that posed by other forms of transport in that the risk to the public is permanent and present along the whole length of the pipeline and in this sense is akin to that of a fixed installation. Pipelines are however a form of transport and the risks involved could and perhaps should be compared with those for other forms of transport.

With regard to controls it is our view that the provisions of the Health and Safety at Work Act, which includes, as relevant statutory provisions, the safety sections of the Pipe-line Act 1962, provides an adequate statutory system. It is also our understanding that attention has been paid in recent years to the major hazard aspects of pipelines, both by the HSE and the Pipelines Inspectorate.

V Air

We are satisfied that the dangerous substances transported by air in themselves do not constitute a major hazard to the public. There may however be some merit in considering how the comprehensive controls exercised over all aspects of air traffic may have useful lessons to offer to other modes of transport.

Conclusions

Despite the obvious and significant differences in the circumstances of the various modes of transport, we found that certain themes recurred. In each field the authorities appeared to be introducing additional controls designed to prevent loss of containment, to give precise warning of the dangers if this occurred, and to prescribe emergency measures to counteract it if it did occur. Less attention appeared to be paid to the conditions under which dangerous substances were handled between various phases of their journey, e.g. at staging posts, in marshalling yards, etc and this is an area which we noted particularly as calling for investigation in all modes. Loading and unloading concerned us in particular. Here there were some obvious sources of potential hazard, e.g. failure of temporary connections. We were not convinced that responsibilities were always clearly defined and properly allocated when the loads were being transferred.

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* We understand that this is now current practice for the Severn Tunnel.

There are several practical considerations which limit the available means of transport in any particular case. Safety is important, and although any method finally chosen must be safe enough, the relative margins of safety between methods may well not be a decisive factor. In the short time so far available to us we have not tried to establish any facts on the relative safety of different systems of transport for the same substance. Even if only one method of transport is practicable, in a given case, then the route which is used can be of prime importance in reducing the number of people at risk.

Thus we believe that the major hazards aspects of the transport of hazardous substances should receive further consideration. In our preliminary study the following areas have appeared to us to merit further consideration; there may be others:

(a) The application of hazard surveys in a way similar to that we have already recommended for fixed installations and in particular to

(i) parking or overnight storage sites (transit depots). This has special relevance for road and rail transport.

(ii) loading and unloading. This applies to road, rail and sea but the last should receive special consideration in view of the vast quantities that are transferred in a relatively short time.

(iii) the movement of hazardous quantities of material as an identifiable unit.

(b) The planning arrangements for

(i) transit depots (road and rail)

(ii) loading/unloading sites (all forms of transport)

(iii) nearby developments which may be affected by (a) and (b).

(c) The interrelationship and effectiveness of the various systems of control and the responsibilities for the various aspects of sea transport in ports and harbours.

(d) The feasibility of comparing risks in various forms of transport.

(e) The possibility of routeing to minimise the risk to the public.

(f) The need to provide adequate communication to and from the person in control of the hazardous cargo in transport to ensure prompt response in the event of an incident.

The Health and Safety Commission is invited to consider if further investigation is necessary.

Annex

SHIPPING

				Quantity		*Consequences*			
Date of incident	*Location*	*Area/site*	*Substance*	*Total available*	*Actually released*	*Nature of incident*		*Fatalities*	*Source of information*
16 January 1976	Landskrona Sweden ("Rene 16")	Docks	Anhydrous Ammonia	533 tonnes	180 tonnes	Rupture of rubber liquid hose	Release, formation of toxic cloud	2	Ammonia Plant Safety Vol 19(1977)
30 December 1978	Sullom Voe Shetland (Esso Bernicia)	Terminal Jetty	Fuel Oil	-	1174 tonnes	Ship collided with jetty	Fuel tank ruptured and contents released on to sea	0	New Scientist 26 April 1979
8 January 1979	Bantry Bay Ireland (Betelgeuse)	Terminal Jetty	Heavy crude oil, light crude oil	75,000 tonnes 40,000 tonnes	? ?	Incorrect ballasting caused corroded hull to buckle	Fire and explosion of cargo vapours	50	Official Enquiry Report
30 August 1979	Good Hope Louisiana USA (Inca Tapuo Yupanqui, Panama City)	Mississippi River	General cargo Butane	600 tonnes (7,000 barrels)	600 tonnes (7,000 barrels)	Freighter collided with barge, ruptured butane tanks	Butane exploded and formed fireball	12	NTSB Report

SHIPPING

				Quantity		*Consequences*			
Date of incident	*Location*	*Area/site*	*Substance*	*Total available*	*Actually released*	*Nature of incident*		*Fatalities*	*Source of information*
24 July 1980	Rotterdam Holland (Energy Concentration)	Terminal Jetty	Crude Oil	150,000 tonnes	?	Incorrect unloading caused vessel to split amidships and sink	No fire or explosion	0	Press Reports
3 August 1981	Solent Nr Southampton UK (Melpo Lemos)	Inland Waters	Crude Oil	150,000 tonnes	—	Vessel ran aground	No release of cargo	0	Lloyds Report

RAIL

28 June 1959	Meldrim Georgia USA	Rural/ Picnic Area	LPG	36 tonnes	18 tonnes	Derailment Tank ruptured by coupler	Tank breached and released contents, minor explosions and subsequent flash-fire	23	Interstate Commerce Commission Report
18 February 1969	Crete Nebraska, USA	Urban	Anhydrous Ammonia	90 tonnes	90 tonnes	Derailment Tank fractured on impact.	Total release of contents to form toxic cloud	3 from derailment 6 from exposure to toxic cloud	NTSB Report
21 January 1970	Belle W. Virginia USA	Urban	Anhydrous Ammonia	75 tonnes	75 tonnes	Tank car collision and puncture of tank	Total release of contents to form toxic cloud	0	Safety in Ammonia Plants — 1970
19 July 1974	Decatur Illinois USA	Urban (Rail yard)	Isobutane	69 tonnes	69 tonnes	Tank car collision and puncture of tank.	Total release of contents, ignition of cloud and explosion	7	NTSB Report
10 November 1979	Mississauga Canada	Urban	11 Tanks Propane 3 Tanks Toluene 4 Caustic Soda 1 Tank Chlorine 3 Tanks Styrene	90 tonnes	70 tonnes	Derailment of mixed freight wagons. 3 propane tanks exploded	Explosion and fire ruptured propane tankers & chlorine tanker which leaked contents — 250,000 persons evacuated	0	Chemical Age Press Cuttings
31 July 1981	San Luis Potosi Mexico	Urban (Railway Station)	Mixed freight including Chlorine (6 vehicles)	3,200 tonnes	90–150 tonnes	Derailment and tank breached	Release of contents to form toxic cloud which spread over wide area	14–20 deaths 280 affected by toxic vapours but subsequently recovered.	Press Cuttings

ROAD

				Quantity		*Consequences*			
Date of incident	*Location*	*Area/site*	*Substance*	*Total available*	*Actually released*	*Nature of incident*		*Fatalities*	*Source of information*
25 July 1962	New Berlin New York USA	Urban	Propane	13 tonnes	13 tonnes	Failure of tank caused by jack-knifing on collision with tree	Release of tank contents resulted in fire	10	NFPA Quarterly July 1963
21 August 1968	Lievin France	Urban	Ammonia	19 tonnes	19 tonnes	Tank collapsed due to corrosion and stress fatigue	Release of tank contents to form cloud	6	Ammonia Plant Safety Vol 12. AICLE
23 October 1970	Hull, UK	Urban	Propane	2 tonnes	0.1 tonnes	Control valve and protective dome of tank sheared off in collision with subway roof.	Partial release of tank contents to form cloud and subsequent flash fire.	2	Police Report
8 December 1972	Nr Wigan UK	Rural	Oleum	20 tonnes	15 tonnes	Tanker collided with another vehicle in thick fog	Tank ripped by corner of the other vehicle, contents leaked out, pool formed with heavy fumes	1	Press Report
11 May 1976	Houston Texas USA	Urban	Ammonia	19 tonnes	19 tonnes	Vehicle crashed and fell 30 feet. Tank ruptured on impact	Release of contents to form cloud	6	City of Houston Health Dept Review
4 January 1978	Nr. Hatfield UK	Rural	Petrol	19 tonnes	19 tonnes	Vehicle involved in multiple crash and tank ruptured	Release of contents followed by ignition and fireball	0	Press Report
11 July 1978	San Carlos Spain	Nr Camp Site	Propylene	22 tonnes	22 tonnes	Rupture of over-filled tank	Release of contents followed by by ignition and flowing fireball	200	Press Report
16 July 1978	Nr. Tula Mexico	Rural	Butane	4–23 tonnes	4–23 tonnes	Vehicle crashed and over-turned. Tank ruptured	Release of contents followed by ignition and explosion	10–15	Press Report

PIPELINE

9 December 1970	Port Hudson Missouri USA	Rural	Propane	—	360 tonnes	Pipe-line failed due to corrosion	Contents released	0	USA Dept of the Interior — Report
22 February 1973	Austin Texas USA	Rural	Natural Gas Liquids (Methane to Hexanes)	—	530 tonnes	Pipe-line failed due to pipe stress	Contents released and ignited	6	NTSB Report PAR–73–4
21 May 1974	Meridian Mississippi USA	Rural	Natural Gas	—	?	Pipe-line failed due to internal corrosion and embrittlement	Contents released and ignited	5	NTSB Report PAR–76–1

PIPELINE

Date of incident	Location	Area/site	Substance	Quantity Total available	 Actually released	Consequences Nature of incident		Fatalities	Source of information
12 May 1975	Devers Texas USA	Rural	Ethane/ Propane Mixture	—	800 tonnes	Pipe-line failed due to pipe stress	Contents released, ignited and subsequent explosion	4	NTSB Report PAR-76-5
20 July 1977	Ruff Creek Pennsylvania USA	Rural	Propane	—	145 tonnes	Pipeline failed due to stress corrosion cracking.	Contents released, ignited and caused flash fire	2	NTSB Report PAR-78-1
4 August 1978	Donnellson Iowa USA	Rural	Propane	—	300 tonnes	Pipeline failed due to combined stresses and weakening of line caused by a dent and gouge	Contents released and ignited	3	NTSB Report PAR-79-1

Appendix 3 The EC Directive on the major accident hazards of certain industrial activities: a brief outline

Directive's scope

The EC Directive is concerned with the protection from major accidents of the health and safety of persons at work and others likely to be affected, and with the protection of the environment. It applies to industrial activities defined in two ways.

The first definition is in terms of a wide range of processes which cover most manufacturing or production activities involving certain dangerous substances. The relevant substances are set out in Annex III to the Directive with appropriate threshold quantities at and above which the various requirements apply.

The second definition of industrial activity is isolated storage involving some named dangerous substances at specified threshold quantities. These substances are set out in Annex II to the Directive.

General requirements

There are two general requirements. The first requires the person in control of any industrial activity where a major accident might occur to be able to provide at any time evidence which shows that major accident hazards have been identified; that steps have been taken to prevent such accidents, and that persons working on site have been provided with the information, training and equipment necessary for their safety. This requirement supplements the general duties imposed on employers by the HSW Act.

The second general requirement requires manufacturers to inform the 'competent authority' i.e. in the UK the HSE, immediately of any major accident. Further information will also be required on the effects of the accident, the emergency measures taken and of any steps taken to alleviate medium or long-term effects and to prevent a recurrence of the accident. This requirement is not linked to any threshold level. This information about major accidents will be passed on to the European Commission who are to establish a register of major accidents for the use of Member States.

Special requirements for larger installations

There are major requirements applying to installations classified as presenting a special potential for a major accident. These fall mainly on the manufacturer who must

(a) produce a written report (or 'safety case') on the hazards and their control,

(b) prepare an emergency plan for dealing with accidents and emergencies at his site and

(c) provide information to people who might be affected by an accident.

In addition a competent authority is required to draw up an emergency plan for dealing with the off-site effects of major accidents.

The Directive requires people who are liable to be affected by a major accident to be informed of the safety measures and of the correct behaviour to adopt in the event of an accident.

Timescales

The Directive required that by 8 January 1984 the requirements should apply for new industrial activities.

For existing industrial activities all the requirements are expected to apply from 8 January 1985 with the exception of the requirement for a written report which must be fulfilled by 8 July 1989 at the latest.

Appendix 4 Transit warehouses: the Morley incident

(by The Advisory Committee on Major Hazards — Working Group E)

On Satuday 13 February 1982 a fire occurred at Quarry Lane, Woodkirk, Morley, Leeds in a warehouse storing paraquat and diquat-based herbicides contained in drums, plastic bottles and cardboard cartons, and also octylphenol in paper sacks. Though the fire brigade responded promptly an intense fire developed which consumed the octylphenol and much of the wooden pallet storage system. The fire resulted in a quarter of the herbicide stock being liberated, which drained, together with fire fighting water, into a water course in close proximity to housing. Widespread environmental pollution resulted from the incident when the River Calder became contaminated. The herbicide-saturated warehouse foundations continued as a source of contamination during rain storms long after the main consequences of the incident had been realised. No one was injured.

After studying all available information we wish to express our concern about a number of issues. Firstly, in relation to the major accident hazards defined in the Seveso Directive the incident was small, but we feel that it may indicate future trends. The Directive requires potential environmental damage resulting from major hazard operations to be considered and such incidents to be reported though the chemicals involved at Woodkirk are not named in the Directive.

Secondly, we are concerned that there is no appropriate system for the control of such warehousing, both in terms of siting and operation. The incident illustrated the need for appropriate site location and construction to provide containment in the event of a release of toxic chemicals, possibly diluted by fire fighting water, to prevent the contamination of natural drainage courses and potable water. This reflects also on the means of site access. In the incident the only site access road became contaminated soon after the fire started, thereby hampering fire fighting operations. We appreciate the numerous difficulties in establishing proper control over transit warehouse operations but are not satisfied that the present system of self regulation is adequate.

Thirdly, concerning management aspects, we feel that as with chemical manufacturing plant someone with appropriate chemical expertise should be available on site to ensure that potential fire, explosion or toxic hazards are appreciated.

Fourthly, we wish to comment concerning the storage of drums containing hazardous substances on sites devoted to distribution. The two principal requirements are that the storage location within the warehouse or yard is arranged so that fire or chemical interactions are minimised, and that an up-to-date inventory for each substance is maintained to ensure that guideline or notifiable levels are not exceeded. We would also wish to see the labels of those drums, bottles, cartons and bags which are destined for overseas markets bearing adequate English language descriptions to aid the emergency services when attending an incident in this country, before export.

Fifthly, though forensic investigations have failed to establish the cause of the fire in this case, one of the potential ignition sources examined was the caravan used as office accommodation stationed within the warehouse. Portable buildings and caravans used within large buildings have been implicated in many fire incidents and we wish to highlight the potential fire hazard posed by their use in such circumstances.

Appendix 5 The effects of loss of containment: emission

(by B Fletcher — HSE)

The topics covered by this phase of the work make up what may be called the source term; this term defines the physical composition of the emission as well as the rate of emission.

The situation we are concerned with is that in which a breach occurs in a fluid-storage vessel or its associated pipework. The storage may be at ambient pressure and maintained by refrigeration, or at ambient temperature and maintained under pressure, or possibly at some intermediate combination of temperature and pressure.

A fully refrigerated liquefied gas requires the addition of heat from an external source in order to evolve vapour. This source of heat is initially the ground or the walls of any secondary containment into which the liquid falls. The initial vaporisation rate is high and decreases thereafter as the contacted surfaces cool down. The source term for the dispersion calculation is therefore time dependent. The geometry and the thermal properties of the secondary containment (if any) will influence the magnitude of the source term. Judicious design can limit this magnitude and thus provides scope for control.

With a pressurised liquefied gas, a proportion of the liquid will flash to vapour on release of the pressure. The liquid that remains will be at its boiling point at atmospheric pressure and will require heat transfer from an external source to produce vapour. The flash evaporation process will be vigorous and will result in fragmentation of some or all of the remaining liquid into finely-dispersed droplets. Surrounding air will be entrained in the process and sensible heat will therefore be available from this entrained air to cause further evaporation over and above the theoretical flash proportion. The production of fine droplets makes the flammable liquid readily available to any flame that may result.

There is a variety of possible release conditions depending on whether the breach is above or below the liquid level, the size of the breach in relation to the cross section of the vessel, the storage conditions and the physical properties of the material. A detailed discussion of the various circumstances, with particular reference to ammonia as an example, is given by Griffiths and Kaiser (1979).

The releases from the vapour space have been under investigation at the HSE laboratories and a recent paper (Fletcher, 1982) presented at a symposium on major hazard summarises the position. Even for small superheats (several degrees) very little liquid would be left in a vessel which fails such that discharge takes place through a hole which is large compared with the vessel cross-sectional area. In this case the liquid can be in the form of large drops which would fall back to the ground; as the superheat increases the droplet size will decrease and at large superheats the cloud could remain airborne as an evaporating aerosol. Estimates have been made using the HSE results on vapour discharge through small holes of the amount of liquid likely to be left in a ruptured container e.g. a railcar. Work has also been carried out at the Polytechnic of the South Bank by Nolan and Bradley (1982) on instantaneous catastrophic releases, and further research proposals are being submitted to the Science and Engineering Research Council. These include measurements of vapour, liquid and aerosol content and also variation of the droplet size of the aerosol spray with time.

In the case of discharges from below the liquid level a considerable amount of work has been done in the past, mainly using water, to determine mass flow rates for two phase flows and to establish calculational techniques (see Henry 1981). These models usually assume homogeneous flow and equilibrium between the phases; this is probably a reasonable assumption for long pipes. Work by Fauske (1965) has shown that the mass flow rate of saturated and subcooled liquids passing through sharp edged orifices can be accurately described by the incompressible flow equation. For flow through short tubes Fauske (1965) showed that residence time within the tube has an effect and for this region there is no generally accepted model. Work is being carried out at the HSE laboratories on discharges from below the liquid level.

Work on discharges from below the liquid level has been confined to those through tubes with a diameter of the order of a few millimetres. HSE has made proposals to the EEC Commission for sponsorship of larger scale experiments.

Jagger and Kaiser (1980) have attempted to link a model of the cloud formation phase with that for the dispersion phase but the lack of experimental evidence is presently a considerable inhibiting factor. The effect of storage conditions on cloud formation has also been considered by Hardee and Lee (1975) and by Maurer *et al* (1977).

In the case of spillage of fully refrigerated liquid, the vapour formation is governed by heat transfer to the liquid from the surfaces with which the liquid comes into contact. There is rather less initial dilution of the vapour by entrained air during the formation stage than is the case with a flashing liquid. Indeed, any dilution that there might be is ignored in estimating the initial cloud or plume properties. The initial conditions will be time dependent as, with increasing time from release, the contacting surfaces reduce in temperature and the heat transfer rate falls. This is especially so if there is a secondary containment such as a bund able to retain all the released liquid.

A literature survey of two-phase flashing jet flow has been carried out by Appleton (1982) under an HSE/SRD contract. Current models and computational procedures of the inception process, the jet structure and the subsequent entrainment process have been examined. No model was found which account for air entrainment.

Areas which may be identifiable as ones in which further research could be carried out are atmospheric entrainment into flashing jets and the composition of flashing jets. The latter topic may form the natural extension to the work being carried out at the HSE laboratories at present.

In each of the scenarios outlined above the spillage may result in the formation of a pool of evaporating liquid. An HSE/SRD Agency agreement project on the fundamentals of evaporation from pools is about to begin. The objective will be to produce an updated version of the computer code SPILL by carrying out a fundamental survey of the spread and evaporation of pools of cryogenic and non-cryogenic liquids on land and water and to validate this against available experimental data.

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Appendix 6 Heavy gas dispersion

(by N C Harris — formerly ICI plc)

Some of the major releases of hazardous substances can lead to the formation of clouds of gas which are heavier than air. This is caused either by the material normally being a gas that has a density greater than air, or because in the release of a liquefied gas, liquid spray or aerosol formation has caused the air to be cooled below ambient towards the liquid boiling point, so creating a cloud of cold dense air and gas. The dispersion properties of dense clouds are known to differ from normal atmospheric dispersion, and accordingly the HSE mounted a series of tests in 1978 at Porton Down, where the dispersion of sudden releases of 40m^3 of heavy gases was studied and some concentration data obtained. Since the scale of these experiments was very much less than that which might occur in accidents at present scales of operations, the HSE have undertaken a project, in conjunction with over 30 sponsors drawn from industry and other organisations around the world, to release 2000m^3 of heavy gas in further experiments on the former airfield at Thorney Island in southern England. A major increase in the number and quality of gas detectors used enabled much better gas dispersion data to be obtained. The results of these tests are to be analysed and submitted to the sponsors, but will later be published.

Our Research Group and HSE have maintained contact with other organisations conducting large scale experiments, and those by Shell Research at Maplin Sands in the UK and by the US Dept of Energy at China Lake in California are of particular relevance in providing comparable data for study.

Contact has also been established with many of those who have developed mathematical models to describe heavier than air gas dispersion, an area in which there has now been considerable progress over the last decade, and where good quality dispersion data from field experiments has been invaluable in refining the models and assisting in establishing satisfactory validation of them. In recent years, a major part of the examination of these models has been carried out by Prof J Havens of the University of Arkansas on behalf of the US Coast Guard, and he is linking this with a study of the experimental work in wind and water tunnels also being conducted in various parts of the world. He has found it possible to establish the broad set of mathematical equations of conservation etc which provide the nucleus of reasonable models and to indicate outstanding areas of uncertainty.

One of the main problems arises as a result of the complexity of the overall situation. In order to restrict the number and type of variables which could interfere with both experimental examination and mathematical modelling of dispersion, one has almost invariably considered only flat open and uniform terrain, yet in the real world this so seldom applies. However it is both necessary and essentially practical to examine the mechanisms of turbulence and dispersion in the simplest situation possible initially. When they have been reasonably established, a situation which is fast approaching, the examination can be extended to some of the more important perturbations. The two which are expected to have the most frequent and dominant effect are those of ground slope (or terrain) and ground obstructions.

Some of these effects are already quite well known, but generally only in a qualitative way, and there is still a need to obtain some quantitative data especially for those features where the effect can be significant. However it is known that heavy gas clouds do not when dense move uphill except with moderate or stronger winds, and they may even roll down a hill against slight winds.

In considering what should be the future objectives in this field of research, it is necessary to look closely at the data available from past accidents. Although some of it is sparse and potentially useful information may be non-existent, there are some incidents recorded, either in reports or through the camera, where vital information can be obtained. One of the most critical areas is in establishing how a release of hazardous material occurs, and how it forms a gas cloud in close proximity to the point of escape, usually before the wind carries it away. It is now well established that the mechanism of release can have a significant effect on the subsequent dispersion of the cloud. For instance the mechanism can dictate whether a large release of ammonia forms a low lying dense cloud, or a more normal cloud which may lift off. The variety of potential mechanisms is large, but there is a real need to understand these much better than can be done at present, to the extent that some limited research could be justified.

The second area, already referred to, is that of the effects of terrain and topography. Although every situation presents a different set of circumstances, there is currently little guidance available to indicate how and to what extent these effects can improve or inhibit the normal dispersion processes in the free flowing atmosphere. It is considered desirable to support some research on these effects, to the point at which adequate guidance can be obtained for a reasonable cost. To go any further would command disproportionate resources and the information would be applicable to a limited number of circumstances in a very few locations.

The cost of the recent full scale experiments at Thorney Island, China Lake and Maplin Sands is enormous, and cannot be further justified unless shown to be essential. This requires the objective to be clear, and cheaper alternative methods shown to be unsuitable. At the present time, the use of wind tunnels is seen as a very cost effective method of examining a wide variety of situations quickly and at moderate cost, and is to be recommended as the preferred method of continuing this research. It will also be essential to use the full-scale experimental data obtained in recent tests to check the scaling laws for these wind tunnels, an aspect of some uncertainty at the present time. This work has already started, and should be encouraged.

Only after this stage in research, using wind tunnels, should any consideration be given to the possibility of further full-scale tests. It will be desirable for any such tests to be mounted on an international scale, without duplication of effort, and the Committee note with satisfaction the moves in the USA towards this end.

Appendix 7 Research on unconfined vapour cloud explosions

(by Dr H Phillips — HSE)

Research on unconfined vapour cloud explosions (UVCEs) is proceeding throughout the world and many other groups are concerned with topics of a general combustion nature which have a bearing on certain aspects of UVCE behaviour. Of direct interest are the works on blast generation, blast effects on structures and the characterisation of the hazard potential of the flammable materials that might be involved. Ancilliary work of importance includes that on flame propagation (deflagration and detonation) through gases and aerosols and that on ignition processes.

Current research

Research has been aimed at an understanding of UVCE's to improve the analysis of accidents and to enable the prediction of the nature and effects of such explosions in a wide range of industrial environments.

To this end research of direct concern can be classified as follows:

(a) experimental simulation of unconfined explosions;

(b) computer simulation of unconfined explosions;

(c) mechanisms for increasing flame speed and blast over-pressure;

(d) effect of blast on structures, and

(e) classification of flammable gases and vapours according to their degree of hazard.

(a) A few organisations have undertaken experimental simulations of unconfined explosion. A feature of all the experiments is that in the absence of turbulence promoters the measured over-pressures have been insignificant, frequently being too low to measure. With turbulence promoters somewhat higher over-pressures have been recorded but still not sufficiently high to explain accidental blast damage. Higher pressures have been obtained but only with reactive gases, such as acetylene and with violent initiation by an explosive charge.

(b) Many computer simulations of unconfined explosions have been undertaken and work is continuing. The typical approach is to assume a flame speed or burning velocity and to compute the blast over-pressure generated. To obtain 1 bar over-pressure within the flame, required to explain the far field damage (see Second Report (1979)) requires a flame speed of over 300 m/s corresponding to a burning velocity of over 40 m/s. It is only with extreme difficulty that such high burning velocity can be achieved in the laboratory and it is unlikely that turbulence can augment burning velocity so much in an unconfined explosion. The Second Report suggests a maximum over-pressure of 1 bar, which is sufficient to explain the damage to many of the structures at Flixborough. However within the explosion there was evidence of higher pressure. Gugan (1979) suggested up to 20 bar but this is now believed to be an over-estimate. Phillips (1981) re-examined the data and considered 6 to 7 bar to be more realistic. Such over-pressure requires a very high burning velocity and to incorporate these into the computation demands adjustment to the algorithm to over-come numerical instability.

(c) High over-pressure can be predicted by computation with the assumption that burned and unburned gases move at different velocities within a thick burning zone — Phillips (1982). Under certain conditions, such as exceeding a certain volumetric heat release rate and with a suitable initiation, this leads to flame acceleration, with the final speed depending on the reactivity of the fuel and the size of the cloud. High over-pressure, 6 bar or more, is predicted. The results of computation suggest that experimental verification would require a vapour cloud much larger than has been used to date. Other means for augmenting burning velocity in an unconfined explosion have been suggested. Bray and Moss (1981) recognise that the burned and unburned gas move at different speeds and they surmise that turbulence is generated at the interface, leading to an increase in heat release rate and in some circumstances to flame acceleration. Moore and Weinberg (1981) suggest that thermal radiation ahead of the flame can heat small particles, such as particles of thermal insulation material, to provide new centres of ignition ahead of the main flame. Only a few such centres are required to give significant increase in blast over-pressure.

(d) Work on the effect of blast on structures is in its infancy. Much data is available on the effects of blast from military explosives, but the blast from the unconfined vapour cloud explosion has a more gradual pressure rise and a longer duration. Studies are in progress to compute the pressure loading on structures of complex shape. Experiments have started within the HSE on the reaction of simple structures to explosion blast with emphasis on aspects of the strength of materials.

(e) A classification of flammable gases and vapours according to their degree of hazard was made on an intuitive basis by T.N.O. in the Netherlands for the preparation of the Dutch Yellow Book. A system of classification based on the critical tube diameter required to initiate spherical detonation has been suggested (Lee, 1981). The critical initiation energy for spherical detonation has also been explored (Bull *et al*, 1977).

Future trends

Much of the earlier work fails to explain the damage caused in accidents, but points out deficiencies in the classical approach to the study of flames and explosion. It is only in the last few years that the difficulties are being surmounted. There is now a prospect of being able to explain or predict the course of a vapour cloud explosion.

Present work is concentrated in three broad areas:

(a) understanding of flame acceleration,

(b) simulations of non-spherical explosions and

(c) blast loading on structures.

(a) Further work is required to understand the acceleration of flame to the high speeds needed to give realistic blast damage, and the effects of the early stages of the explosion on its subsequent acceleration. Further experimental studies are planned but a computer simulation seems to offer the best approach in the immediate future.

(b) The simulation of non-spherical explosions is still in early stages. Simple rules for evaluating blast are available but more rigorous treatments are planned. Rigorous computer solutions of the flow equations in two and three dimensions are likely to be large and expensive and future work will centre on procedures for simplification.

(c) Computation to predict blast-loadings on structures can be made in two dimensions and work is planned to enable predictions to be made of the interaction of a blast wave with a three-dimensional structure.

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Appendix 8 Catastrophic fires

(All papers included in this Appendix are by the Advisory Committee on Major Hazards — Working Group E)

In the context of major hazards installations a catastrophic fire is distinguished by the area likely to be affected, intensity, the speed of development, location or a combination of these factors.

We are concerned with potential incidents having serious consequences in terms of damage to the population and the environment, such as conflagrations, fire balls and fire storms, all of which come within the definition of a catastrophic fire. These fires are conceived as being outside the range of severity of industrial fires most usually encountered.

Conflagrations involving industrial cellulose nitrate (nitrocellulose)

The Explosives Act 1875 applies to guncotton which is the name given to nitrated cellulose, usually cotton, made into solid propellants for ammunition, rocket motors and into commercial and military explosives. Less highly nitrated grades of cellulose nitrate are used for industrial purposes and these are exempt from the controls of the Explosives Act provided that not less than 85% of the material is soluble in ether and alcohol, it contains less than 12.3% nitrogen and is uniformly mixed with not less than one third of its weight of certain liquids, or is in solution, or is gelatinised with not less than 18% of a plasticiser. These measures confer some stability on the inherently unstable substance to render it safer to store and handle. Because of its ability to form strong cohesive films, industrial cellulose nitrate is mainly used in the paint and printing ink industries. Some celluloid is still produced and there are relatively large stocks of cellulose nitrate based cinema films held in the special stores of film archives.

Industrial cellulose nitrate does not need air for combustion, the nitrate groups within the molecule supply sufficient oxygen. In the dry state it is easily ignited by a flame, sparks, impact or friction. It burns extremely rapidly with a very hot flame and if ignited in a confined space will generate gas pressure with explosive violence. Self-sustaining decomposition can occur. The gases produced by decomposition are both flammable and toxic, and can explode if mixed with the requisite amount of air and the mixture ignited in a confined space.

Industrial cellulose nitrate is packed by the makers into steel or fibre-board drums and is dampened with water or with isopropyl or butyl alcohol or is plasticised. The kind and the amount of dampening material considerably influences the rate of burning. If the protection of the dampening medium is lost due to physical damage to the drums or because the dampening medium migrates, the cellulose nitrate will dry out and then the hazards are greatly increased. Spilled dampened material can dry out and be ignited by friction, for example. The use of flammable liquids as dampening media introduces the additional potential hazard of the flammability of the vapours. Alcohol dampened material is usually packed in a polythene liner within the drum whereas plasticised material is not packed in polythene because of electrostatic hazard. The fastenings of the drum lids are designed to relieve internal pressures in excess of 3 bars.

Tests have shown marked differences in behaviour in fire of alcohol dampened industrial cellulose nitrate depending whether it is packed into steel or fibre-board drums. In fire the contents of the steel drums were ejected and burned extremely rapidly with fireball-like behaviour and a burning time of 1 to 2 minutes. In contrast, the same material in a fibre-board drum burned relatively quietly for about 30 minutes. The plasticised material behaved similarly in fire whether packed in steel or fibre-board drums. It burned very vigorously but without the fireball-like behaviour exhibited by the alcohol-wet material.

In 1973 almost 400 te of alcohol-wet cellulose nitrate packed in steel drums and stored in the open air caught fire. Scorching and blistering to wooden structures was experienced at distances up to 140m but it is possible that some of this damage was caused by radiation from secondary fires.

Fireballs

The Second Report of the Advisory Committee on Major Hazards drew attention to the dangers associated with fireballs and suggested that further study of this phenomenon was desirable. Since then a number of papers have appeared describing the results of theoretical and practical investigations and reviewing the available literature. (1–9)

It is useful, at this point, to describe the catalogue of possible events which could follow the sudden failure of a pressurised container holding flammable material. When a flammable gas or vaporising liquid escapes from a vessel under pressure it mixes progressively with the air as it moves away from the sources of escape. Should it be ignited, what happens will depend upon the stage in the mixing process at which ignition takes place.

If the source of ignition is remote from the source of escape, mixing will have progressed and it is an explosive cloud that is ignited. Burning proceeds quickly through the mixture of fuel and air. If the mixed cloud involves tonnes of flammable material an unconfined explosion may occur, accompanied by significant pressure effects. If the cloud is small, burning occurs smoothly, although rapidly, and the result may be described as a flash fire or burning vapour cloud. In any event, to be engulfed in the resulting flame is likely to prove fatal.

If on the other hand the issuing flammable material is ignited near to its source of escape, burning and mixing progress together. Should the rate of discharge of fuel be rapid, the flame becomes turbulent and intense and 'lift off' from the source of escape may occur, resulting in a mushroom-like formation. This is known as a fireball.

In the past, there have been a number of fireballs immediately following a BLEVE (boiling liquid, expanding vapour explosion) when this has resulted from the engulfment in fire of a vessel containing flammable vaporising liquid (such as LPG). As a fire is already present, early ignition of the material emerging from the bursting vessel is assured.

It appears from the review papers cited that there is general agreement on the size of a fireball from a given release of fuel, but a fairly wide variation in opinion concerning the effective duration and the surface emissive power. It seems likely, however, that both these parameters could be influenced by the nature of the release and the mass of material released. For the purposes of calculating levels of thermal radiation, most workers assume spherical geometry and it can be demonstrated that this assumption is reasonably valid for distances of significance in the study of major hazards.

At present it is possible to calculate levels of thermal radiation based on parameters derived from small scale experiments and empirical calculations. To improve or validate these conclusions, larger scale experiments are required to relate rate of growth, effective duration and surface emissive power to the pressure and mass of the material released. Work is also necessary to establish the relationship between atmospheric attenuation of thermal radiation over a range of atmospheric conditions and flame temperatures or surface emissive powers. There is a considerable need for research in the field of the effects of thermal radiation on people.

Fire storms

We have noted that there is considerable literature on fire storms but that the discussion has scarcely, if at all, involved specialists in the fields of major chemical hazards. The discussion has been concerned in the main with problems of civil defence or with forest fires.

Such an event involves the firing of a high proportion of buildings over a large area within a short space of time. As a result of the convective currents the draughting of the fire is enhanced, giving rise to high temperatures and high peripheral winds, sometimes of hurricane force. Some of the most serious fire storms in history occurred during World War II, initiated by heavy bombing raids on German and Japanese cities. The death tolls in these fires were at least an order of magnitude greater than those associated with conventional bombing. The Group concludes that the fire storm phenomenon is real, and believes that it may also have occurred in peace time during city fires.

In wartime, fire storms were associated with the dropping of high explosive bombs which shattered buildings and hampered the work of fire fighters, alternating with the dropping of incendiary bombs. Certain German cities were vulnerable to the establishment of fire storms because multiple ignitions occurred within a short time (up to, say, two or three hours) in areas of high density of buildings with narrow streets.

The Group note that there are many and considerable differences between conditions affecting the initiation and response to wartime and peace time events of a fire storm nature.

We consider that the layout of modern chemical and process plant is unlikely to provide the conditions necessary for a fire storm and to affect populated areas solely as a result of conventional fire spread.

We however consider that there are some grounds for believing that a fire storm in a surrounding urban area could be initiated by a spillage of a few hundred tonnes of liquid oxygen. We recommend therefore detailed study of the fire storm potential of liquid oxygen spillages.

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Appendix 9 Dust explosions

(by the Advisory Committee on Major Hazards — Working Group E)

The question which Group E addressed was: "Are there installations in the UK which have major hazard potential through the medium of dust explosions?" What follows is a summary of the Group's deliberations in an attempt to answer the question. The underground workings of coal mines are excluded in what follows because these have been subject to close enquiry by other agencies, and present no hazard to the general public.

Dust explosions have usually, but not exclusively, taken place in premises processing grain into animal or human foodstuffs. The fatalities are usually the result of the collapse of buildings or structures, and to this extent the effects are localised. Materials which present a risk of a dust explosion are, however, to be found in a wide range of industries. It is generally considered that the potential hazard exists in the circumstances of the production of sugar, starch and flour where large quantities of flammable dusts are processed in tall or multi-storied structures of heavy construction. Premises in which large quantities of aluminium or magnesium powder are processed are a matter of particular concern, as these materials have in the past produced explosions of exceptional severity. The incidents involving dusts or powders usually have effects which could be termed local and have therefore been excluded from the provisions of the proposed notification regulations.

Some incidents

There have been few major incidents involving flammable dusts in the UK. A summary of these accidents is given in Table 1 below. Excepting two of the 1911 incidents all those killed were workpeople on the premises.

Table 1 Major UK dust explosions

		Within premises		*Outside premises*	
Year	*Location*	*Killed*	*Injured**	*Killed*	*Injured**
1911	Glasgow	2	3	3	5
1911	Liverpool	37	100	2	1
1911	Manchester	3	5	–	–
1913	Manchester	3	5	–	–
1930	Liverpool	11	32	–	–
1941	Liverpool	6	40	–	–
1964	Paisley	5	2	–	–
1965	London	5	32	–	–

For comparison with the figures reported in Table 1, 15 were killed and 599 injured in the 18 year period 1962–1979 in 1176 relatively minor incidents reported as involving flammable dusts, 474 being explosions and the remainder were fires. The ratio of killed to injured in these incidents is low. For example, in the UK in this period 25 persons were killed, 10 of them in 2 incidents, and there were 633 people injured in all.

Similar major explosions have occurred overseas. For example in 1919 at a starch/corn plant at Cedar Rapids USA, 43 persons were killed, and in 1942 at a similar plant in Peking, Illinois, USA, 42 persons were killed. More recent US grain elevator explosion statistics are given in Table 2.

Table 2 Recent explosions in US grain handling facilities

Year	*Killed*	*Injured*	*Number of explosions*
1974	7	47	12
1975	65	84	21
1976	22	82	27
1977	4	19	9
1978	13	37	15

Two incidents in the USA, one in 1917, and another in 1929, each resulted in 8 fatalities from explosions involving metal powder dust clouds.

World wide experience indicates that to be injured by a dust explosion one has to be close to the affected premises; dust explosions tend to destroy the often large buildings containing the plant but their effects are localised. This is reflected by the comparatively low incidence of off-site casualties as shown in Table 1.

Industrial processes involving flammable dusts can be divided into those in which dusts:

(a) are an integral part of the manufacture, such as the fine dust produced by grinding, or

(b) arise as a by-product of processing.

Unlike explosive gas mixtures, the partial volume of dust required for an explosion is very small. For a number of reasons the explosives range for dusts is much wider than for vapours. It is dust particles smaller than 200 microns which result in potentially hazardous conditions. The smaller the particle, generally, the greater the danger. Confinement volume and geometry are significant parameters in dust explosions, as is the exposed dust surface area. The dusts from wheat, soya and maize, which have produced big damaging explosions, are easier to ignite than coal dust.

The true potential for a dust explosion resulting from an industrial process lies in the volume of the dust cloud that exists in confined conditions. The design capacity of a silo for stored material (viz sugar) gives a rough guide to the potential for explosion, but a nearly empty silo, for the reasons given above, gives rise to a much more hazadous situation than one which is nearly full. It is not only in the interior of silos that the hazard of explosion arises. Fine dust which escapes from plant can settle in the surrounding building enclosure and any substantial accumulations within a building, sufficient to create a flammable cloud on resuspension, can cause an explosion severe enough to destroy the building. Thus a relatively minor explosion may create a much more serious incident by resuspending and igniting the accumulated flammable dust in air. The demolition of the building containing the plant causes many of the casualties. Thus, good housekeeping is vital in buildings containing the plant handling flammable dust.

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* *Definition of injury* In the period from 1906 until 1937 it was mandatory to report to the District Inspector of Factories any accident of sufficient severity to disable an employee from working at his ordinary work for more than seven days. In 1937 the qualifying period was reduced from seven to three days.

Though a number of major explosions in the USA during 1977–78 focussed considerable attention on grain silos, we consider that conditions in the UK differ widely from those in the USA. UK grain silos are smaller in size and number than those in the USA. Also, the intermittent nature of UK operations does not put maintenance under pressure, as in the USA. The maintenance aspect is considered most important for good explosion prevention. International collaborative work is at present investigating the pressure rise developed during silo explosions with a view to providing guidance as to the venting requirements of large silos.

The possibility that hazards may arise in the future because of increases in the production and transportation of pulverised coal is recognised. This fuel type is beginning to be used on a world-wide scale. The UK may become a distribution point for such fuel, which could be of concern if it became a megatonne per annum trade.

The Group recognise that best current practice comprises:

(a) the elimination of the hazard (eg by the use of water slurries),

(b) planned explosion protection (eg the incorporation of adequate explosion relief vents on plant, the use of automatic explosion suppression systems, inerting the atmosphere, or by making the plant strong enough to resist any internal explosion), and

(c) eliminating the risk of serious secondary explosion by siting plant in the open air. Where this would not be practicable the plant should be contained within lightly sheeted, strongly framed buildings, or the buildings themselves should be provided with adequate explosion relief.

Our conclusions are:

(a) We consider that the potential for dust explosion incidents exists quite widely in the UK and that, judging from the records of incidents and casualties, the hazards are being well controlled by means of Section 31 of the Factories Act 1961 (see Annex 1). However, vigilance must not be relaxed nor opportunities to effect improvements be neglected.

(b) The conditions relating to UK grain silos are such that silo explosions of the frequency and type experienced in the USA during recent years are most unlikely in the UK.

(c) We call attention to the best current practices outlined above.

(d) We call attention to the services offered for the determination of dust explosibility described in Annex 2. Advice on precautions may be obtained from the Fire Research Station or from the local office of the Health and Safety Executive.

Annex I Extract from Factories Act 1961 Part II

Section 31

(1) Where, in connection with any grinding, sieving, or other process giving rise to dust, there may escape dust of such a character and to such an extent as to be liable to explode on ignition, all practicable steps shall be taken to prevent such an explosion by enclosure of the plant used in the process, and by removal or prevention of accumulation of any dust that may escape in spite of the enclosure, and by exclusion or effective enclosure of possible sources of ignition.

(2) Where there is present in any plant used in any such process as aforesaid dust of such a character and of such an extent as to be liable to explode on ignition, then, unless the plant is so constructed as to withstand the pressure likely to be produced by any such explosion, all practicable steps shall be taken to restrict the spread and effects of such an explosion by the provision, in connection with the plant, of chokes, baffles and vents, or other equally effective appliances.

(4) No plant, tank or vessel which contains or has contained any explosive or inflammable substance shall be subjected —

(a) to any welding, brazing or soldering operation;

(b) to any cutting operation which involves the application of heat; or

(c) to any operation involving the application of heat for the purpose of taking part or removing the plant, tank or vessel or any part of it;

until all practicable steps have been taken to remove the substance and any fumes arising from it, or to render them non-explosive or non-inflammable; and if any plant, tank or vessel has been subjected to any such operation, no explosive or inflammable substance shall be allowed to enter the plant, tank or vessel until the metal has cooled sufficiently to prevent any risk of igniting the substance.

Annex 2 Dust explosibility assessment

Tests are available at the Fire Research Station for the assessment of a range of dust explosibility parameters. These include classification tests and measurement of maximum explosion pressure, minimum ignition temperature, minimum ignition energy and minimum explosible concentration. Tests are commissioned on a sponsored basis and the methods used have been agreed with HM Factory Inspectorate.

By means of this service, industrial and official enquirers are able to have samples of dusts and powders assessed accordingly to officially published methods. Manufacturers of powders use the service in meeting their requirements under the HSW Act.

In addition to explosibility assessment, the Fire Research Station also carries out research into the validity of proposed changes to test methods and also on the methods of protection against dust explosion.

Testing and information services are also available from specialist commercial undertakings and the appropriate departments of certain universities.

Appendix 10 Domino effect

(by the Advisory Committee on Major Hazards — Working Group E)

The domino or 'knock-on' effect refers to a loss of containment incident which interferes with the operation of other adjacent plant so that further loss of containment occurs. This hazard was identified in our First Report (para 13). We have reviewed available material and conclude that the circumstances surrounding such postulated events require examination on an individual basis.

For example, a small leak of flammable gas may ignite and the flame impinge on a large vessel, leading to a large spill of hazardous substance. Protective systems may be destroyed by flame impingement and missiles from disrupting machinery may breach containment. Ship accidents in port areas or coastal waters close to land may adversely affect operations on ships in neighbouring berths or operation of plant on land.

These effects were demonstrated in an accident in the harbour at Texas City in 1947. The cargo of ammonium nitrate on the SS *Grandcamp* exploded, causing a tidal wave 5m high which flooded the nearby Monsanto Chemical Company. In addition, burning debris from the SS *Grandcamp* started a fire on the SS *High Flyer*, berthed 214m away. The cargo of the SS *High Flyer* included both sulphur and ammonium nitrate and subsequently exploded, destroying the ship.

Accidents on one industrial site can affect operations on nearby industrial sites. An example of this effect was provided by the Flixborough disaster in 1974 when the explosion on the Nypro site caused a loss of cooling water to blast furnaces at a nearby British Steel plant.

We are of the opinion that it should be standard practice that everyone operating plant where a major accident could occur should consider the effects of such events on other plants on their site or a nearby site and that all those affected should plan accordingly to minimise the consequences. The provisions of the EC Directive on Major Hazards of Certain Industrial Activities require manufacturers to notify competent national authorities of all aspects of such activities. The activities must also be examined for domino effects.

We feel that the methodology used in the process industry should be used in such hazard reviews. Such analyses were used in the Canvey Island investigations.

Appendix 11 The siting of developments in the vicinities of major hazards: HSE's draft guidelines to planning authorities

(by the Health and Safety Executive — Major Hazards Assessment Unit)

Introduction

The control of risks from major hazards may be achieved in various ways, for example:

(a) limit the amount of hazardous material present;

(b) reduce the likelihood of an accidental release of material;

(c) plan for emergencies, and

(d) reduce the number of people exposed to risk.

Some of these measures may be taken within the installation, particularly at the project planning stage.

In many cases the situation in the installations is already fixed and the scope for improvement under HSW Act is fully utilised. Even so, there may remain some residual risk. It may still be desirable to control the number of people exposed to that risk. It is unlikely that the residual risk could justify the removal of existing populations by the termination of viable land uses. However, it is possible to inhibit an increase in the population at risk by control of new developments under planning legislation.

It is the purpose of HSE's advice to facilitate planning control where appropriate. Planning authorities are expected to include the factor of risk in their consideration of a planning decision. Thus the types of development near major hazards should be deliberately chosen to minimise the population at risk.

HSE takes as a starting point the assumption that the major hazard installation complies with the requirements of HSW Act. It is then necessary to assess the level of residual risk to a proposed development in the vicinity, and to judge whether this might be a significant factor in the planning decision. HSE's assessment takes account of the consequences and likelihoods of various accident scenarios, and the implications of variations in vulnerability between different types of development. In some cases the assumption of compliance with HSW Act implies a precise standard.

In other cases the standards are not precisely defined, or it may be possible to comply in a variety of ways. The individual characteristics of installations are taken into account where possible, but there are limits to the amount of detail which can be considered. It may be necessary to assume average performance in the absence of obvious individual variations, or for cases which are being assessed on paper.

This note deals only with the provision of advice on proposals for new developments in the vicinity of existing major hazards. The assessment techniques are used in a similar way when considering the siting of new major hazards in relation to existing buildings, but the judgement of the significance of the risks may be different. For example, the siting of a new major hazard may be constrained by the need to integrate it with existing plant. The application of a simple 'reciprocal rule' for the siting of new major hazards would neglect the differences in availability of sites for the two situations. There is also the possibility of seeking special safety standards on a new plant to facilitate its siting.

Assessment: likelihood and consequences of an accident

The first part of the assessment is objective in the sense that it does not include social or political judgements, but it does include estimates of various factors where data is more or less unavailable. Thus it includes technical judgement by professional risk assessors. There is inevitably some uncertainty introduced by this judgement process and by lack of precision in basic data. This does not prevent the derivation of reasonable conclusions but it does imply that some caution is necessary. The technical judgements may tend to lead to an over-estimate of the risk level. If a planning decision is finely balanced, a more detailed review of assumptions may be worthwhile.

Assessments of risk from different materials differ in detail but they have many features in common. The basic sequences of events for LPG and chlorine are:

LPG: Plant failure — release — vaporisation — mixture with air — ignition — explosion and/or fire — blast and/or heat propagation — impact (either directly on people, or on buildings which collapse or burn).

Chlorine: Plant failure — release — vaporisation — mixture with air — travel downwind — dilution — inhalation — injury.

The risks from such sequences can be evaluated in two main ways, namely historical and analytical. In the historical approach, information from past incidents is used to predict the risks. The Second Report of the Advisory Committee contains information on some past incidents, and it derives a "Mortality Index" to indicate the average number of fatalities per tonne of material released. This approach may be useful to devise a hazard rating for a material, but it is noticeable that the average index conceals a wide variation between cases and it is thus of questionable value for predicting individual situations. Other problems with the historical approach are the small number of cases and the incompleteness of information on cases, so it may therefore provide a rather poor statistical basis. This approach might be difficult to adapt for prediction in situations different from those already included by the accidents.

The alternative, analytical, approach attempts to synthesise the risk on the basis of sequences outlined above. This approach is complex and it requires assumptions to be made in the absence of data. Also, it may be difficult to select appropriate scenarios to include. It is of course possible to combine the approaches, and in practice this is what is done. The historical approach is used to provide information on the likelihoods of releases, while the analytical approach is used to predict consequences.

To illustrate the approach, the example of bulk pressurised LPG is used. Installations of this type comprise the majority of the major hazards in Britain, and the risks from them are relatively straightforward to assess. The assessment might begin by listing the various possible releases, either by quantity (short release e.g. tank burst) or by rate (long release e.g. uncontrolled pipe-split). There is a continuous range of possible release, but this can usually be simplified by identifying obvious sub-divisions. For the LPG case we might have:

Event	*Probability*	*Consequences*
Minor flange or gland weeping	Quite likely	Not felt off-site
Pipework break	Rather unlikely especially for major cases	Localised, but could extend off-site from major cases
Tank burst: BLEVE	Very unlikely	May be harmful at considerable distances off-site
Tank burst: UVCE (delayed ignition)	Extremely unlikely	"
Tank burst: drifting gas clouds	Extremely unlikely	"

It is now necessary to determine more precisely what are the probabilities and consequence of these events. Obviously there could be wide variations between individual plants and between events in each sub-division. For example, the effects from pipe-break might depend on: size of hole; duration before shut-off; whether liquid gaseous or two-phase; wind-speed; delay before ignition; dispersion to below flammable limits; type of combustion, and site-specific features. To simplify the problem, assumptions are made to give an indication of the realistic outcome from the most severe event within a sub-division.

The consequences in terms of likelihood of injury are derived by firstly calculating the impact intensity of the heat or blast at a particular distance, then relating this to the vulnerability of the population at that distance. The possibility is noted that different types of building, having different populations, might give different degrees of protection from any given intensity.

The result of this process is a list of events and risks. A decision can then be made on which events are trivial in that no injury could result. For remaining events, the consequences are considered in conjunction with the likelihood, to determine the combined risk of release and injury. This completes the objective assessment.

It should be noted that this approach does not automatically rule out from consideration any type of source event, however unlikely. Even the largest, most unlikely events are included, so there is not necessarily any cut-off corresponding to a "maximum credible accident". However, attention is paid to the combined risks, which may be very small from an unlikely event, so that the largest events are not necessarily significant determinants of the overall risk. In practice, assessments may be based on one or two events which may thus appear to correspond to "maximum credible accidents"; this implies that lesser events may be more damaging but they are so unlikely as to present negligible extra risk. For the LPG example, separation distance guidelines for the siting of the first category of development near existing installations tend to be based on the provision of substantial protection from BLEVE and UVCE; this automatically gives a very high degree of protection from pipe-break and lesser events.

Assessment: types of development

It was indicated earlier that different types of building may have associated with them populations whose vulnerabilities differ. This may be of great importance in a siting judgement. HSE feels that it would be inappropriate to advise against all forms of new development near major hazards nor need new major hazards be sited away from all existing buildings. Types of developments may be distinguished by various factors which relate to the risks, for example:

(a) whether residential, workplace, recreational, shopping etc;

(b) length of time any individual may be present;

(c) number of people who may be present and duration of occupancy;

(d) ease of evacuation;

(e) inherent vulnerability of people e.g. elderly, disabled, children, and

(f) physical factors e.g. building height, materials of construction etc.

On the basis of these factors, HSE identifies three main categories of development. The first consists of developments where users would be present for most of the time, or where large numbers could be present at any one time, or where people are particularly vulnerable. Examples include housing, shopping centres or very large retail outlets, multi-storey office blocks etc. The second category consists of less sensitive developments and includes industrial developments with low employment density, warehouses etc. HSE also identifies a third category containing special cases such as hospitals, schools and other particularly vulnerable developments, to which particular attention should be paid in siting judgements.

It is normally advised that planning control is only necessary in respect of the first and third categories of developments near major hazard installations. There are various mitigating factors associated with the second category, such that it would be difficult to argue that the risks to users justify inhibition of this type of land-use. These factors could include ease of evacuation, low occupancy-time, fitness of population (e.g. adult workforce), small number of people, building protection or building not hazardous to occupants, etc.

Summary of MHAU's advice

For LPG and similar flammable liquefied gases, HSE recommends separation distance limits such that the consequences of minor releases at the limit would not be injurious, while the consequences of major releases (BLEVE, UVCE) would be unlikely to seriously injure more than a small fraction of the exposed population. In principle, unignited vapour clouds could travel to the limit, or even beyond it in unfavourable weather conditions, and people enveloped in a cloud would probably be seriously injured, but the risk to an individual from such a scenario is very low.

For chlorine, HSE recommends separation distance limits such that the consequences of major pipework failures would be unlikely to seriously injure more than a small fraction of the population downwind, in typical prevailing weather conditions. In unfavourable weather, or with larger releases from tank failure, people at greater distances could be injured, but the risk to an individual from such a scenario is very low.

Presentation of advice

In presenting its advice, HSE attempts to give planning authorities clear guidance on the weight to be attached to the factor of safety. HSE tends to use one of three graded responses as follows:

Situation 1 (negligible risk): No significant reasons for refusing planning permission.

Situation 2 (marginal risk): The risks are very small and are not in themselves sufficient grounds for refusing planning permission, but they could be a factor against the development to add to any other adverse factors. This would apply near the outer limit of separation distance, or with small developments.

Situation 3 (substantial risk): While the probability of a serious incident is low, the consequences at the proposed development site could be serious. The safety issue should be a major factor and the planning authority is advised not to grant planning permission. If there were other factors which weighed strongly in favour of the application, HSE would seek to explain the technical assessment and level of risk in more detail before the planning authority's decision was made. (In exceptional cases of Situation 3, where the planning authority was minded to grant permission contrary to HSE's advice, HSE might consider whether to request a planning inquiry where the issues could be examined in detail in a public forum.)

It often happens that an initial unfavourable response from HSE leads to discussions of the scope for modifications to reduce the risk. Significant reduction may enable HSE to advise favourably. In other cases, HSE may give a conditional response, with advice on the use of planning conditions to ensure that the risk is reduced.

Appendix 12 Hardware reliability: incident reporting and assessed reliability

(by Professor F P Lees)

It is convenient to consider hardware and human reliability separately, but it is recognised that ultimately any failure in a man-made system may be regarded in a sense as a human failure.

There are a number of aspects of hardware reliability on which research would be useful. First, there is need for a taxonomy, or perhaps better, a model of major accidents which can be used as a basis for the investigation of accidents and the collection of data. Second, guidelines based on this taxonomy or model are required for the reporting of accidents so that the information given indicates the significant features and thus provides useful data. Third, analyses of such reports are needed in order to give a better understanding of the particular types of failure which result in major accidents. Fourth, there are certain failure and event rates and probabilities which are critical in hazard assessments and on which better data are required. Fifth, a better understanding is needed of the current numerical limits of engineering feasibility and of the factors which determine these limits. Sixth, there needs to be more work done to demonstrate the validity of the hazard assessments which are made. These points are now considered in turn.

There is a clear need for a system of classification of major accidents on hazardous installations. In many disciplines such a classification is based on a taxonomy. However, a taxonomy consists of a set of mutually exclusive categories, whereas an accident is usually the result of a combination of features, as the typical fault tree demonstrates. What is wanted, therefore, is an accident structure model which will probably resemble a fault tree in that it contains logic gates but which is general and hence applicable to all accidents.

Some of the characteristics of major accidents which such a model would need to take into account may be illustrated as follows. In general, a hazardous release occurs only if there is an inventory of hazardous material, a failure of containment and failures of protection by hardware and by people. The failure may be one which occurs within the design parameters or outside them. It may be a mechanical failure, a process failure or a failure due to an external event or a rare phenomenon. Failure of protection by hardware may occur due to lack of, design defect in, disabling of or equipment failure in such protection. Failure of protection by people may occur due to failure of procedures or failure of initiative. Procedure failures include lack of, design defect in, neglect of and failure in execution of the procedure. Mechanical failures may be those of design, fabrication or installation and construction or those of inspection, maintenance and modification. Process failures may be those of normal operation, abnormal operation or liaison with mechanical functions. Some of these failures are events which initiate an accident sequence, others are events which negate mitigating features which normally prevent the sequence from propagating. Failures of inspection, of procedures and of protection by hardware and by people are particularly important categories of failure of mitigating features.

Current practice in the investigation and reporting of major accidents leaves much to be desired. Reports are often incomplete and unbalanced and draw misleading conclusions. Given a suitable accident model it should be possible to devise guidelines for improved accident reporting.

The implementation of such guidelines should result in a greatly improved data base for major accidents. One important use of the data base would be to obtain by statistical analysis a better understanding of causes of these accidents. Another important use would be to obtain data on certain failures and events which are critical in hazard assessment but which are currently subject to considerable uncertainty.

A number of organisations are involved in the creation of data banks for accident reports, failure data, etc, relevant to major hazards and contact should be maintained with such work. There are also developments in computer technology which may also be relevant. These include not only keyword information retrieval systems but also expert systems.

The question of the numerical limits of the reliability to which it is feasible to engineer plant is important. There are various limits given in the literature by engineers involved in quantitative assessment, but it would be useful if these could be clarified both with respect to the type of accident envisaged and to the features which limit the reliability attainable. The latter is certainly affected by features such as common cause failures but the relation between such features and reliability limits is unclear.

There is now a considerable amount of activity in hazard assessment, but relatively little work has been done to validate the risk estimates which are made and there are many who remain sceptical. More needs to be done to validate the methodology. It is appreciated that the realisation of a major hazard is a rare event and that validation of the assessment up to this point is not practical, but it should be possible to do more to validate assessments of lesser events which are critical to the major accident.

Appendix 13 Human reliability

(by D C Thomas — HSE)

The role of the human in the safety aspects of industrial systems is being realised and accepted more and more. However, the research and its subsequent application is still fragmented and narrowly applied to specific tasks and industries. There is no national programme for this work in the UK which attempts to coordinate the studies in human factors. If the UK intends to enhance the awareness of industry in the importance of human factors in safety and to encourage the application of relevant research, then some respected group should be established to act as a UK focal point for the whole area of human factor studies. At present, the Human Factors in Reliability Group and the Ergonomics Society are possible forums for reviewing, publicising and encouraging the application of human factors research efforts.

Much effort has and is still being devoted to the operator and his control room environment and tends to be very specific in content. It is therefore necessary to broaden the areas of interest to those upon which the operator is dependent. These include plant inspection and maintenance, design and the whole area of management and organisational performance which pervades the activities previously mentioned. We feel that the performance of an individual is inseparable from the management/organisation performance. Any assessment should also be monitored through-out the life-cycle of both the plant and the organisation.

As with any other type of assessment, there is a need to structure this subject area of study. There is still a lack of good models to facilitate the understanding, analysis and prediction of the whole area of human and management performance. The behaviour of individuals and organisations is very complex and hence simple solutions, such as better ergonomics or more automation, do not necessarily provide the best answers. To assess the human factors aspect of safety some form of quantification is needed. This raises the problems of data acquisition (sources and techniques for obtaining data) and its validation. Objective data will be difficult to obtain; therefore research into the techniques for acquiring subjective data is probably the most fruitful area. Calibration/validation of models and data would require further studies. There is also a need to develop some agreed form of terminology and classification for this subject ie a taxonomy. There is still room for progress in this area.

Once some structure has been achieved, it will be possible to identify, in a more refined and certain manner, the key human factor components which affect the safe operation of a system as well as their relative importance.

All of this work will be only of academic value unless some effort and strategies are forthcoming to encourage industry to apply the findings of the research work. There is a significant need to forge research and development links between pure research and field application by industry. Possible reinforcement of these links could be via a UK forum or coordinating group, industry trade associations and Government advisory and regulatory bodies.

Other areas of concern are the need to develop better aids for improving human performance such as training and documentation to support current ergonomic research. Due account should be made of the human capability for error recovery, much work has to be done in this area. It should not be forgotten that emergency planning is dominated by individual and organisational performance as well as the response of those affected by the hazard. Again, there is much work to be done in this area.

It is fortunate that both in the UK and internationally there are now attempts to bring order to the whole area of human factors research but the problem of applying the outcomes by industry has yet to be tackled.

Appendix 14 Computerised data banks for major hazard incidents

(by G Bagshaw, Dr B A Maguire and Dr C Nussey — all HSE)

Introduction

A recurring theme in the many discussions of Group D of the ACMH has been the concern that vital information, knowledge and experience regarding major hazards may not be available to be applied in particular situations for a variety of reasons; these include the possibility that the knowledge has been forgotten possibly as a result of retirements or transfers of staff etc. Sometimes, the knowledge may be available but not known about or easily accessible by the person needing it. For example, it may be buried in filing systems, archives and libraries from which if sufficient time and effort are available it could be retrieved. In some cases, there is a lack of will to extract data because the effort is too great and the immediate incentives not sufficiently great for the organisation to allocate the necessary resources.

This problem is not, of course, unique to information on major hazards but is common to many areas of human knowledge where large amounts of information and data have been accumulated over the years. The modern approach to such problems is to computerise the information into a database which allows the information to be searched quickly by the associated information-retrieval programs, ie software. For example, many libraries, including those in HSE, are now using databases for storing large amounts of information and to enable literature searches to be conducted efficiently and quickly. This paper considers the use of information storage and retrieval systems for major hazard applications.

Information retrieval techniques

The main advantage of computer-based information-retrieval systems is that they allow large databases to be searched quickly and retrieve and list those items which are of interest to the user. Such facilities are achieved either by making use of a general-purpose information-retrieval system, or by writing special-purpose software to satisfy the specific needs of the application (such software often makes use of database management systems provided by computer manufacturers etc). The former technique allows systems to be set up quickly with little programming effort, provides great flexibility but can be relatively costly in terms of usage of computer resources.

The latter technique tends to make more efficient usage of computer resources but systems can be expensive to set up and may suffer from lack of flexibility. Examples of general-purpose systems are Harwell's STATUS (AERE, 1982) and ICI'S IRIS (Flynn and Wild 1977), STATUS is used in HSE Library Catalogue, LIBCAT, which contains about 32 000 references at the present time. LIBCAT will contain of course some bibliographic references to published material relating to major hazards but as it was designed as a general-purpose library system, this material is not comprehensive.

Bibliographic references are only one source of useful information. In the next section, consideration is given to what information might be required in the area of major hazards.

What information is needed on major hazards?

The type of information needed about major hazards will depend on *who* wants it and *why* they want it. These questions need to be answered before a comprehensive answer can be given about *what* is required and *how* it can be stored and retrieved. Thus, it is unlikely that any one system could meet the needs of industry and an enforcing organisation such as HSE.

For example, industry may need information on major hazards to assist in matters such as:

(a) the design of safe plants (learning from past experience to prevent major incidents);

(b) the provision of material for training of personnel;

(c) the preparation of risk assessments;

(d) the provision of necessary protection to plant personnel and members of the public;

(e) devising evacuation and emergency action plans, and

(f) furthering the understanding of the control of major hazards.

On the other hand, HSE may need information on major hazards for reasons such as the following:

(a) to assist in discharging its duties under the HSW Act and specifically the Notification of Installations Handling Hazardous Substances Regulations, 1982;

(b) to assist in discharging its duties under the forthcoming EC Directive on major hazards (information implicit in Appendices 2 and 3 of the forthcoming regulations would be required);

(c) for training and current awareness purposes;

(d) for assisting with the validation of assessments submitted by industry;

(e) to aid decision-making and policy-development;

(f) to assist in its advisory role to local planning authorities and to ensure consistency of that advice;

(g) to assist with the validation of techniques being developed for (d) (e) and (f), and

(h) for assisting with its own risk assessment.

Although these lists are not exhaustive, they demonstrate that there are differences between the two requirements but that there are areas where the type of information needed is very similar. These areas of common interest can be divided into the following four general but dissimilar types:

(a) detailed information about past incidents such as *what* went wrong and *why*, what happened next, details of casualties, consequences and ameliorating factors etc;

(b) probability data for the various failure modes identified by (a) or some other means, e.g. HAZOP study (Lawley, 1974);

(c) experimental and investigative data designed to augment and further the understanding of the causes and consequences of incidents (e.g. large-scale dispersion trials, radiation from pool fires, burning rates of flammable vapour clouds, etc), and

(d) chemical properties (including toxicity) and physical properties of the substances involved.

To the authors' knowledge, purpose-designed commercial databases exist for all of these types of data, except that of type (c) where, to some extent, some published material can be identified through databases such as LIBCAT provided that the publications have been catalogued. There is, perhaps, a need to integrate such data into other databases or establish a new database on the line undertaken by workers in the area of complex turbulent flow (McQuaid, 1982). Examples of existing databases in these and other areas are given later but, before reviewing these, a short discussion on the quality and storage of incident data will be made to give perspective to the general problems being considered.

The quality and storage of data on incidents

At present, information on incidents derives from a variety of sources ranging from police, fire-brigades, companies, insurance and governmental organisations and public inquiries to press cuttings and eye witness accounts. This information is consequently of a variable quality. In the case of public enquiries, the information is likely to be detailed and verbose; with press cuttings the data may be incomplete, sometimes biased and even unreliable or inadequate. Therefore, care must be taken to ensure that data used on incidents is of the minimum standard acceptable for the particular database. This information can, in general, be divided into two broad types: textual (narrative accounts) and numeric (dates, times, quantities etc).

The way in which this information is used to create a database on hazardous incidents will be largely determined by the objectives laid down for the database as determined by user requirement (ie *who* wants it and *why*). Specification of the user requirement is by no means a simple task and must take into account the availability of data, the cost of computerising, storing and retrieving the information, the availability of suitable software and the benefits likely to be derived from a particular need.

The user requirement, in essence, determines the structure of the database and the types of software that will be suitable to manage the database and retrieve data from it. In the case of an incidents database, it would be expected that information should concentrate mainly on causes and consequences and the associated factors.

Although such information may be described in narrative accounts, the retrieval of relevant documents to some extent is hindered by the variety of ways in which it is possible to describe essentially similar events. It will therefore, be usually necessary to bring some degree of structure to the database so as to provide a high degree of *recall* (i.e. to retrieve all relevant incidents) coupled with a high degree of *precision* (minimal useless information, i.e. 'false drops'). This structure can be provided by including user-defined keywords or classifications in the form of numeric codes so that important characteristics of the incident can be readily identified. The extent to which structure can be included in the database is determined by the capability of the software to be used in handling such information and the availability of resources for conducting the associated labour intensive pre-processing of the data.

Numerical structured (coded) information can be used for readily producing statistical summaries of incidents which would be more laborious to produce if the database were of a largely unstructured form. In addition, coded data can be stored much more efficiently on a computer. However, structuring the data in this way presents other problems apart from that of effort. It is a source of error and much professional judgement is required if a consistent approach is to be maintained in classifying information which is written in a variety of styles and levels of detail.

At present, the standards of reporting incidents vary almost as widely as the type of incidents themselves and one desirable pre-requisite of a data storage system would be some agreed form of incident reporting, possibly on the lines of those proposed by Roberts (1980). There is no doubt that such a proposal, if adopted internationally, would greatly improve the quality of information on incidents. However, an internationally agreed reporting form would probably need the support of the United Nations agencies and is likely to take some considerable time to achieve. However limited progress through the ECSC may be possible.

Some existing databases

The authors cannot claim to have made an extensive survey of all relevant databases but the following give some idea of the situation in the UK.

(a) *Incident databases*

There are at least two commercial databases which claim to provide international coverage of incidents etc. One is the TNO Industrial Safety Databank (called FACTS) which is based in Apeldoorn, Holland (Bockholts, 1982). This is an off-line service, enquiries being made by telephone, telex or letter. The other is the CHAFINCH (1982) system provided by the commercial bureau SIA Computer Service in the UK.

The suppliers of CHAFINCH claim that the database contains information on "chemical accidents, failure incidents and chemical hazards providing international coverage of transportation, storage and processing of oil, gas, petrochemicals and other hazardous substances". CHAFINCH is an on-line system held on SIA's IBM mainframe computer which is accessed by computer terminals via the public telephone network. In October 1981, the database contained information on 640 incidents.

(b) *Event probability databases*

The National Centre for Systems Reliability of the UKAEA's Safety and Reliability Directorate has, since 1960, maintained and updated a database containing reliability data for a wide range of nuclear, chemical and other plant components. The database is known as the Systems Reliability Service (SRS) Data Bank and is in two main parts: the Event Data Store and the Reliability Data Store (SRS, 1980). It provides information to the contributors of data on the performance, availability and reliability of their own plants and generic reliability data for use in SRS studies or by associate members of SRS. Currently, the database contains about 10 000 entries covering over a quarter of a million failures (SRS, 1982).

FACTS also offers data for probability calculations.

(c) *Property databases*

Two UK databases of this type are known to the authors. The one used currently within HSE is Physical Property Data Service (PPDS) which is maintained by the Institution of Chemical Engineers and is available through a number of commercial bureaux. PPDS will supply properties of pure compounds and calculate the properties of mixtures using standard mixing rules. The data have been derived by evaluation of published and unpublished data, from sponsored experimental work and from estimation using the best predictive methods available. (If one is only interested in pure compounds, it is usually more efficient to look them up in a reference work.)

A similar type of database is HAZCHEM which is maintained by AERE Harwell.

In addition, HSE are also using the American Society for Testing Materials' computer program CHETAH (CHEmical Thermodynamics And energy Hazard evaluation) for calculation or estimation of thermodynamic properties and the calculation of the maximum possible energy release from a chemical reaction (Treweek *et al* 1978).

(d) *Other databases*

One other database which will be available in January 1983 is ECDIN which has been established by the Joint Research Centre of the Commission of the European Committees at Ispra, Italy. ECDIN (Environmental Chemical Data Information Network) will provide information on environmental chemicals including toxicological effects, manufacturing locations, production and/or consumption figures, counter measures and relevant accidents).

This database should usefully augment FACTS and CHAFINCH.

The Major Hazards Assessment Unit is maintaining, under the STATUS system, its own database on notifiable sites (HAZINST), the database being currently structured around the proposed Hazardous Installations (Notification and Survey) Regulations of 1978.

Conclusions

(a) There would appear to be a number of useful databases already in existence that will meet some of the needs of potential users of information on major hazards.

(b) The most useful databases identified from this survey and within Europe which are generally available are FACTS, CHAFINCH, SRS Reliability Data Store, PPDS, HAZCHEM and ECDIN. Equivalent databases are likely to exist in the USA.

(c) The needs in the areas of physical and chemical properties seem equally catered for by HAZCHEM, PPDS and published reference works. The weakest area would seem to be the toxicological one.

(d) There will always be a need for organisations to maintain, normally or otherwise, purpose-designed information systems to meet their own needs. However, we feel that the number and extent of these can be greatly reduced if the claims made for the commercially available databases, such as FACTS, CHAFINCH and ECDIN, materialise.

(e) Should a purpose-designed information system be needed, we feel that in most cases it could be based on general purpose software (eg STATUS, (AERE, 1982)) or a system-specific database management system.)

(f) We do not claim that this paper covers all angles of the problem or that an in-depth survey of the area has been undertaken.

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